Improving Latex Extraction Technology by Debarking Guayule

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Guayule is a member of the sunflower family, Asteraceae, and belongs to the genus *Parthenium*. Out of the 16 species of *Parthenium*, it is the only one known to produce rubber in any significant quantity (Siddiqui and Locktov 1981). Guayule (*Parthenium argentatum* Gray) stores its rubber primarily within the cells of its bark.

The present rubber extraction method involves rupturing of these cells by grinding the whole plant, but guayule bark constitutes only 30% of the dry weight of the whole shrub. Therefore, harvesting, transporting and processing of plant material other than bark for latex extraction increase cost of field handling, transportation and processing.

Debarking guayule soon after harvesting at the crop site will substantially improve the efficiency of latex extraction technology by reducing costs of transporting material to the processing location and increasing the processing capacity of the latex extraction plant. Introduction of a guayule debarking system will enhance the latex extraction process; hence, the outcome of this research will strongly benefit the industry by saving energy and production costs making rubber production from guayule more commercially viable.

Guayule debarking and separation technology has been developed and tested. The prototype debarking machine requires a single source of power and improvements in capacity by scaling up the design. Further work is needed to provide mobility in the field as well means of attachment to a guayule harvester. The test has indicated that the performance of the separation system can be improved by enlargement of the venturi system and fine tuning of the air velocity and material collection cut-off distances. Moreover, feasibility studies and suitability of the bark processed for high quality latex needs to be investigated.

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**Craig Burns**
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Executive Summary

What the report is about

Guayule is a member of the sunflower family, Asteraceae, and belongs to the genus Parthenium. Out of the 16 species of Parthenium, it is the only one known to produce rubber in any significant quantity (Siddiqui and Locktov 1981). This report discusses the development of an efficient guayule debarking systems, evaluates the effectiveness of the technology and provide appropriate recommendations as to how it can be used to advance commercialisation of guayule.

Implications for relevant stakeholders

To make guayule commercially viable, the establishment, maintenance and processing costs need to be minimised. Debarking guayule in the field and processing only the bark will create a cheaper and more efficient alternative to current harvesting and transportation of a large mass of guayule shrub.

Background

Hevea a tropical rubber tree, is the main source of natural rubber but it has been found to cause life-threatening Type I latex allergy which is triggered by the presence of protein in the latex (Siler and Cornish 1994). This along with ever growing demand for natural rubber has led to a renewed interest in guayule which has been envisioned as an alternative natural rubber plant with commercial potential (Ray 1993). Unlike Hevea latex, guayule latex is hypoallergenic and thus can be used to produce high-value medical products (e.g. surgical gloves, condoms, catheters) that are safe for healthcare workers, patients and consumers (Siler and Cornish 1994). There is also a significant benefit from guayule due to its ability to grow in a wide range of climatic conditions

Aims and objectives

The aim of this project was to develop and demonstrate a practical and economical way of debarking guayule that would be suitable for commercial use.

The specific objectives were to:

1. develop an efficient and reliable debarking machine for guayule
2. make appropriate recommendations for adoption of debarking technology by the guayule industry in Australia and overseas.

Methods used

A guayule debarking system, consisting of a mechanism for feeding and size reduction as well as bark removal units and a separation component (bark from other plant material), was designed and developed.

The bark removal unit consists of a pair of rollers 215mm in diameter and 600mm in length. The rollers were installed with one on top and the other one underneath. The bottom roller was offset by 100mm to the feed side to catch and guide cut stems into the rollers. The rollers rotate in opposite directions at different speeds drawing and crushing the cut stems without chipping the core. The speed of the bottom roller was 500rpm and top roller rotated at 950rpm giving a speed ratio of 1:1.9. The speed difference between the rollers created a shearing action required for peeling the bark. The clearance between the rollers is adjustable and springs are fitted so that the rollers can handle different stem sizes ranging from 6 to 45mm.
The separation unit was designed based on the characteristics of the processed plant material. The inner wood was heavier and dropped out of an air stream at a lesser distance compared to the leaves and bark. The leaves and bark produced similar terminal velocity making air separation much more difficult. However, when allowed to float in a slowly moving current of water, the bark quickly absorbs moisture and sinks while the leaves and dry twigs which are not useful in latex extraction continue floating. This difference was used to separate the bark from leaves and dry twigs.

The separation unit consists of a 4kW fan attached to a 6m long and 150mm diameter metal tubing. A discrimination chamber 1.4m long and 30cm wide was designed and attached to the air supply system for grading processed material by density. The other end of the chamber where lighter material is removed leads to a 40-litre capacity rectangular water trough for flotation.

The debarking system was tested to determine the bark removing performance as well as separation of bark from other processed plant material. A debarking efficiency of up to 95% and maximum separation efficiency of 74.8% was obtained from the evaluation test. The prototype debarking machine also produced a throughput capacity of up to 450kg/h. This capacity can be further increased by scaling up and modification of the current design. The test has demonstrated that feeding rate is critical for performance of the debarking unit and air velocity plays an important role in separation.

**Results/key findings**

The findings in this project have demonstrated that it is possible to significantly reduce transport costs and increase the throughput capacity of latex extraction plant by retaining 60–70% of plant material in the field.

**Recommendations**

Further work on up scaling the prototype debarking system to a commercial field machine will greatly benefit the guayule industry.
Introduction

Rubber is presently an irreplaceable raw material vital to industry, transportation, medicine and defence. About 18 million tonnes of rubber is produced annually worldwide (International Rubber Study Group 2004). Natural rubber constitutes approximately 40% of the global rubber production (Auchter 2000). The remaining 60% is synthetic rubber, which is a petroleum oil based product. The world’s current supply of natural rubber comes entirely from a single rubber species *Hevea brasiliensis*, which is now largely cultivated in the humid tropics of South East Asia.

Natural rubber is commonly used as a raw material for the manufacture of more than 40,000 products, including over 400 medical devices. It possesses high performance properties such as resilience, elasticity, abrasion resistance, efficient heat dispersion, impact resistance, and malleability at cold temperatures (Mooibroek and Cornish 2000; Cornish 2001). *Hevea* a tropical rubber tree, is the main source of natural rubber but it has been found to cause life-threatening Type I latex allergy which is triggered by the presence of protein in the latex (Siler and Cornish 1994). This along with ever growing demand for natural rubber has led to a renewed interest in guayule which has been envisioned as an alternative natural rubber plant with commercial potential (Ray 1993). Unlike *Hevea* latex, guayule latex is hypoallergenic and thus can be used to produce high-value medical products (e.g. surgical gloves, condoms, catheters) that are safe for healthcare workers, patients and consumers (Siler and Cornish 1994). There is also a significant benefit from guayule due to its ability to grow in a wide range of climatic conditions.

More than 6 million hectares of land is suitable for guayule cultivation in Australia. Recent research conducted at the University of Queensland found that new guayule lines can produce rubber yields of up to 800 kg/ha per annum (Dissanayake et al. 2004). Thus, there is huge potential to produce sufficient natural rubber to meet Australian domestic demand and to capture international markets. The availability of large tracts of semi-arid and potentially productive land as well as guayule’s suitability to mechanisation makes guayule production highly attractive in Australia.

Efficient processing of guayule shrub for latex extraction is essential to make a guayule industry commercially viable. Unlike *Hevea*, which bears rubber latex in a system of easily tapped ducts, guayule stores its rubber primarily within the cells of its bark (Wagner and Schloman 1991). The present rubber extraction method involves rupturing of these cells by grinding the whole plant. Guayule bark constitutes only 30% of the dry weight of the whole guayule shrub (Kuruvadi et al. 1997). Therefore, debarking guayule soon after harvesting at the crop site will substantially improve the efficiency of latex extraction technology by reducing transport costs to the processing plant and increasing the processing capacity of the latex extraction plant. Moreover, it creates the possibility of transporting plant material from locations further away from the extraction plants. Storage of bark under low temperature and moisture (Cornish et al. 1999; Nakayama et al. 1999) for future processing will also be simpler requiring less space and resources than for the whole plant.

Introduction of a debarking system for the extraction of guayule latex will be beneficial in saving energy and costs. It will help in making guayule more commercially viable and economical in Australia.
Objectives

The main aim of this project was to develop a practical and economical way of debarking guayule that is suitable for commercial use.

The specific objectives were to:

3. develop an efficient and reliable debarking machine for guayule
4. make appropriate recommendations for adoption of debarking technology by the guayule industry in Australia and overseas.
Review of Literature

Guayule is a member of the sunflower family, Asteraceae, and belongs to the genus *Parthenium*. Out of the 16 species of *Parthenium*, it is the only one known to produce rubber in any significant quantity (Siddiqui and Locktov 1981). Guayule is a bushy shrub and grows to about 1.3 m in height and 1.4 m in width, depending upon the environment (Thompson and Ray 1989). Guayule is a woody xerophytic perennial shrub native to the Chihuahuan Desert of Northern Mexico and West Texas (West et al. 1991). It has narrow leaves alternating along the stem. The leaves are covered in a drought protecting white wax. Guayule bush may survive 30 to 40 years under desert conditions of its native habitat, where annual rainfall may be less than 250 mm (Anon 1977).

Traditionally a drawknife (Figure 1) has been used to manually remove bark from plant stems. With advances in technology various techniques of removing bark from timber logs and small plant stems have been used in the timber industry as well as in some high value industrial crops. Some of the methods used in the timber industry include a drum debarker, ring debarker, and bin debarker. Specialized equipment is used to remove bark from small diameter plant stems.

![Drawknife (Manual debarking)](image)

Source: U.S. Department of Labour (www.osha.gov)

**Figure 1.** Drawknife (Manual debarking)

Methods used for large diameter stems

Drum debarker

A drum debarker can be made as a chainsaw attachment fitted with blades to provide a wide cutting surface on the log (www.logwizard.com). The other type of drum debarker is a rotating cylinder in which stems are debarked by a tumbling action inside the cylinder fitted with a mechanical means to remove the bark.
a) Drum debarker attached to chainsaw drive

b) Blades on drum

c) Rotary drum debarker

Source: U.S. Department of Labour (www.osha.gov)

Figure 2. Drum debarker

Ring debarker

A mechanical ring debarker is currently the most commonly used method in sawmills (Dickinson, 1994). The logs are debarked by a rotating ring with knives scraping the bark from the stem. It is characterised by feed rates up to 125m/min, and the ability to debark a wide range of log species, of varying diameter and length under various operating conditions (green, dry) with minimum fibre loss and log end damage (Dickinson, 1994).
Cradle ring debarker (Figure 3) is a type of ring debarker with a key feature of an open design unlike the drum debarker which uses a covered cylinder. This enables the operator to remove debarked stems and replace with a new stem. The bark is loosened and removed by compression and shear force resulting from the impact of the stems (Sasko 2002).

![Cradle ring debarker](source: www.pulpandpaperonline.com)

**Figure 3. Cradle ring debarker**

**Bin debarker**

Bin debarker consists of a U-shaped chamber that has a series of cylindrical rotors mounted longitudinally on the bottom and/or side. Debarking blades are attached to the rotors at intervals along the rotor length (Arkai 2002).

**Methods used for small diameter plant stems**

**High pressure water jet**

Ultra-high pressure water jet operating at 48 300 kPa through a ring-type No. 6 nozzle with 15° fan and 1.57 mm diameter opening was used for debarking several hard wood species (Krilov 1983). Except *E. plularis*, all species were effectively debarked using this method. Several short logs with average diameters of 65 to 140 mm were successfully debarked using the high pressure water debarker. The major drawback of this method is it requires a large water supply and is generally restricted to operation of considerable size.
**Flail debarker**

The flail debarker utilizes steel chains attached to a rotor to beat the bark off the stems as they pass through the debarking station (Arkai 2002). This technology (Figure 4) is suitable for multi-tree processing of small diameter trees (Lappalainen et al. 2001). The unit features 54, 8-link chains attached to either two or three drums (6 rows of 9 chains per drum) positioned above and below the in-feed rolls to the drum. Bark, limbs, broken tops fall out of the bottom of the unit while the debarked logs are directed into a precision disc chipper. It produces a greater percentage of fine debarked chips compared to the ring debarker (Arkai 2002). A mobile version of this equipment is used for debarking and delimming of multiple, small diameter stems of size ranging from 20 to 25 cm.

The rotational speed of the chain and the feed speed affect the result of debarking. A rotational speed of the chain drum between 300 and 500 rpm successfully removed bark from trees and contact time of the chain with the surface of the tree was less than 5 µs (Lappalainen et al. 2001).

Source: Lappalainen et al. 2001

**Figure 4. Chain-flail debarker**

**Roller mills**

Roller mills are commonly used to crush stems using set of rollers to remove outer bark or crush the whole stem to separate fibre. It is used in kenaf (*Hibiscus cannabinus* L., Malvaceae) processing for fibre production (Webber et al., 2002; Kemble et al. 2002) and crushing of sugarcane stalks for extraction of juice and breaking of cane fibre. Rollers are also used as part of the processing of hemp once it is retted and conditioned (Nebel 1995). Conditioning the bark with low pressure steam to soften the bark followed by compression using steel rollers rotating in opposite direction was also found effective in removing bark from wood chips of red alder (Hillstorm 1974). Separation of the bark from the wood after debarking was carried out using a tumbling cylinder screen and internal impact hammers which produced fine grounds of bark.

**Steaming and beating**

This method has been used in China for bark removal from stems of hemp, mulberry, and paper mulberry (Tsai and Reyden, 1997). The process was used as a preliminary procedure in producing pulp for paper making. It is followed by fermentation, beating pulping and other steps in making paper.
Biodegradation

Treatment of wood using lignin degrading fungi is another method that has been investigated as an alternative to mechanical debarking. A promising result was obtained by growing *Ceriportopsis subvermispora* on aspen and pine (Messner and Srebotnik 1994). Inoculation of fungi loosens the bark without affecting the strength, reduces pitch and protects the wood against staining.

Debarking using chemicals

Pre-treatment of wood with chemicals and enzymes has also been tried to facilitate removal of bark from various types of wood. Spruce and hemlock treated with sodium arsenite resulted in sufficiently loose bark allowing much easier peeling (Berntsen 1954). Treating wood with pectinolytic enzymes also reduced energy requirement for debarking by up to 80% (Raettoe *et al*.1993).

Conclusions

The review of literature suggests that many of the methods used are mainly focused in either removing bark from large sized logs for the timber industry and majority of the techniques used on smaller plant stems are mainly targeted at separating fibre. These methods cannot be directly used for debarking guayule. Moreover, guayule shrub is normally comprised of stems of varying diameter making debarking almost impossible with conventional technology. However, some procedures used in the processing of other plant materials can be modified and adapted in the design of guayule debarking machine.

The high pressure water jet method of debarking may be effective, but involves the use of especially highly-pressureised water in large quantity. Recycling the water may also be expensive because it will involve an intensive purification to avoid blockage of nozzles.

Specific features of guayule and the quality of latex produced needs to be taken into consideration. The design used for debarking has to be suitable for separation of the unwanted material. The debarking machine has to be a unit that can be operated in the field with minimum power requirements and minimum time to prevent dehydration of the bark which can affect latex quality. A debarking machine that will include conveying, size reduction, removal of bark and separation will have a potential for improved pre-processing of guayule shrub.
Establishment of Guayule Plants

Propagation

Guayule seed, harvested from line AZ-2 was selected for its vigour and high rubber yield (Dissanayake et al. 2004). The seed was treated to break dormancy according to the procedure used by Naqvi and Hanson (1980). Seeds were washed and soaked in distilled water for 8 hours followed by a 2 hour treatment with a solution of equal parts of gibberellic acid (200 ppm) and 0.25% NaOCL. Treated seeds were then sown into trays of 100 cells with each cell approximately 22 cm³ in volume. The trays were filled with media consisting of peat, vermiculite and perlite in the proportion of 1:1:1 respectively. Trays were then placed in a propagation room for one week in a controlled temperature of 25°C under fog irrigation. Once the majority of the seeds germinated, the seedlings were transferred to a greenhouse (Figure 5). The seedlings were watered frequently and thinning was carried out after two weeks. When the seedlings were 3 weeks old, they were transferred into tubes of about 136 cm³ in volume using the same media. For about a week before planting, the seedlings were moved out of the greenhouse for hardening.

Field establishment and maintenance

Seedlings were carefully transported to the field and planting was carried out following land preparation and formation of 1.2 m wide raised beds (Figure 6). Beds were covered with plastic mulch to limit weed growth and conserve moisture. Seedlings were planted out in October 2006 and November 2007, about 11 weeks after sowing. The seedlings were planted at a spacing of 1 m between plants and 1.6 m between rows (6250 plants/ha). Transplants were supervised frequently at initial stage and dead plants were replaced. Supplementary irrigation was applied for initial establishment. Plants were irrigated using trickle irrigation to supplement soil moisture. Weed control was carried out both
by mechanical and chemical means. To maintain fertility of the soil, 50 Kg of ammonium sulphate (N=20% and S=24%) and 15 kg/ha of zinc (zinc chelate) were applied with irrigation.

Figure 6. Guayule plants in the field (4 weeks after transplanting) at Gatton, Queensland

Figure 7. Two years old guayule plants in the field at Gatton, Queensland
Design and Development of a Guayule Debarking System

Design criteria

It is important to establish design criteria prior to the development of any machine to enable measurable, clearly-stated goals to be achieved (Christianson and Rohrbach 1986). The following criteria were established for the development of the guayule debarking machine based on information available and the latex quality requirements. The machine should;

- remove guayule bark in a short period of time to minimize dehydration
- be capable of effectively separating detached bark from other plant material
- handle a range of guayule plant stem diameters
- easily be hitched behind or on the front of a tractor and use tractor power
- cause minimal loss of bark.

Preliminary investigations

Before the design and development of the debarking machine, measurements were carried out to find out the diameter of guayule plant stems at different ages of the plant. Guayule plants are generally harvested for rubber production at about 2 years of age. However, stem diameters were measured on plants ranging from 2 to 4 years old to record variations in sizes to be used in the machine design (Table 1). Measurement was done using vernier calipers on five randomly selected plants from four ages. Diameters were measured at the plant base 10 cm from the ground (base), half the height of the plant (mid) and close to the tip of the plant (tip).

Table 1. Stem diameters at different height and age of guayule plant

<table>
<thead>
<tr>
<th>Age</th>
<th>Position</th>
<th>Stem diameter (mm)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 years</td>
<td>Base</td>
<td>45.9</td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>32.4</td>
<td>22.6</td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>8.0</td>
<td>6.5</td>
</tr>
<tr>
<td>3 years</td>
<td>Base</td>
<td>36.1</td>
<td>38.3</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>15.5</td>
<td>19.2</td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>8.6</td>
<td>6.3</td>
</tr>
<tr>
<td>2 years</td>
<td>Base</td>
<td>36.2</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>Mid</td>
<td>20.0</td>
<td>19.7</td>
</tr>
<tr>
<td></td>
<td>Tip</td>
<td>7.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>

* Base: 10 cm from the ground, Mid: half the length of the plant and Tip: 10 cm below the tip of the plant

After a continuous investigation of the nature and behaviour of guayule bark, different techniques of removing bark from the wood were tested through preliminary observations in the laboratory. The options considered included the use of a water jet, crushing between the rollers of a range of surfaces, rubbing action between flat rough surfaces and impact from rotating blades or paddles. The results of these observations are summarised in the following sections.
Water pressure

An effort was made to use water jets to debark guayule using pumps capable of producing high pressure. It was difficult to even crack the bark after trying a pressure of up to 18000 kPa. It appears that a specially made super high pressure water jet system operating at up to 48 300 kPa was needed to crack the bark as reported by Krilov (1983). Such an option can be expensive requiring a filtration system as well as a large volume of water.

Rotary blades or hammers

This method involved repeated beating of guayule stems using rotating blades after reducing the stems in length. The guayule stems were hammered by the rotating blades against a serrated concave. The bark removal was effective with the stem pieces left in the chamber for about 5 seconds before despatching. The method lacks continuity and a batch feeding system is required to produce effective removal of bark. Accuracy of the time required for a given batch is difficult and over crushing produces chipping of the inner wood which is not desirable from a separation point of view.

Rollers

Rollers were found to be more effective in terms of uniformity of bark removal and also for continuity in operation. Therefore, the concept of rollers as a crushing mechanism for loosening and detaching the bark was used in the design of the present debarking system. It was found that metal rollers caused chipping of the inner wood therefore a softer and rough surfaced material for gentle removal of bark and minimum chipping of stems was required.

Machine development

The main parts of the debarking system include feeding, cutting and bark removal and separation units. In the design of the machine, feeding of harvested guayule shrub into the cutting mechanism is achieved by using a set of wheels on a single shaft that roll, grab and hold the branches against the cutting blades. The cutting section was provided to reduce stem size to pieces of uniform length for ease of bark removal. The bark removal unit was designed to crush and peel off the outer bark by passing the stem pieces through a self-adjusting pair of rollers followed by air and water separation to isolate bark from wood.

Feeding unit

The feeding mechanism (Figure 8) is designed to provide the debarking machine with a system that allows the placement of guayule shrub on a deck from which it is then immediately drawn into the cutting mechanism. The delivery of the shrub into the set of cutting blades is aided by a set of equally spaced notched wheels. The speed of rotation was dictated by a variable speed motor (5 to 25 rpm). This arrangement allows a slow and uniform feed of the plant material and effective cutting by holding it against the rotating circular saw blades. A 1.5 m long conveyor belt was later attached to the feeding unit to facilitate delivery of plants to the entrance of the feeding mechanism.
The cutting action is performed by 20 circular saws (Figure 9) arranged vertically on a shaft installed for uniform cutting at a set length. Based on preliminary observations, a cutting length of 5 cm was chosen to provide more effective bark removal. Once the stems are cut at the desired length, the material slides down into the debarking unit by gravity. The speed of rotation of the circular saws was set at 1100 rpm, (based on previous studies). The type of circular saws and speed of rotation were also selected according to the finding by Lungkapin et al. (2007). Their results indicated that highest cutting quality was achieved using circular saw teeth number of more than 60 and a speed of more than 1200 rpm.

The cutting blades used in the debarking machine were of brand name (TWA) Tungsten Carbide Tipped (TCT) and are designed for hard and soft wood with a longer cutting life. Higher teeth number is recommended by the manufacturer for smoother cutting hence, the 80 teeth type was selected. A diameter of 250 mm with bore diameter of 30 mm and thickness of 3 mm (Kerf) was chosen to suit the overall design of the machine. The blades are secured in place by hollow spacers placed between the
circular blades and tightened at the end using a large size nut on a threaded drive shaft against a welded nut at the other end. A cutting metal board of 25 cm wide and 4 mm thick was also fitted at the front of the cutting system. The total width of cutting is 120 cm which was selected on the basis of close to maximum height of a mature guayule shrub.

**Bark removal system**

The bark removal unit consists of a pair of rollers 215 mm in diameter and 600 mm in length (Figure 10). The rollers were installed with one on top and the other one underneath. The bottom roller was offset by 100 mm to the feed side to catch and guide cut stems into the rollers. The rollers rotate in opposite directions at different speeds drawing and crushing the cut stems without chipping the core. The speed of the bottom roller was 500 rpm whereas top roller’s speed was 950 rpm giving a speed ratio of 1:1.9. The speed difference between the rollers created a shearing action required for peeling the bark. The clearance between the rollers is adjustable and springs are fitted so that the rollers can handle different stem sizes ranging from 6 to 45 mm.

The rollers were also covered with a heavy duty belting material “black duck” glued on the surface of the rollers. The belt material had a rough top-grip face pattern and hardness of 30 durometre. The rough pattern was oriented parallel to the longitudinal surface of the rollers. The overall thickness of the rough surface belt material was 6 mm. The purpose of the belt material was for gentle removal of bark and minimal damage to the inner wood. In normal operation the clearance between the pair of rollers is set to provide lower clearance at one end and higher clearance to suit maximum stem diameter at the other end. The gap between the rollers was chosen based on preliminary observations as 1.6 mm at the plant base and 0.6 mm where the shrub tip is entering. Two springs with a load constant of 61.7 kN/m and displacement range of 0 to 7.5 cm were installed at each end of the upper roller to accommodate stems of different diameters. The shrub is fed in such a way that it is laid on the cutting board or feeding conveyor with the base of the plant at the higher clearance end and the tip of the plant at the lower clearance end for effective debarking.

**Figure 10.** Bark removal system

**Separation unit**

The separation unit was designed based on the characteristics of the processed plant material. The inner wood was heavier and dropped out of the air stream at a lesser distance compared to the leaves and bark. The leaves and bark produced similar terminal velocity making air separation much more difficult. However, when allowed to float in a slowly moving current of water, the bark quickly
(absorbs moisture and sinks while the leaves and dry twigs which are not useful in latex extraction continued to float. This difference was used to separate the bark from leaves and dry twigs.

The separation unit consists of a 4kW fan attached to a metal tubing 6m long and 150 mm in diameter. The metal tubing has a 3m straight section, a 2m curve length to raise it to a level of a discrimination chamber and a 1m length under the material feed hopper (Figure 11). The discrimination chamber is 1.4 m long and 30 cm wide with a lighter material outlet leading to a 40 litre capacity rectangular water trough. The trough has a screen attachment set at 45° slope to filter the water and remove floating material. The filtered water then flows into another container for recycling. A recycling pump is placed for pumping water back to the flotation trough. The amount of air required for pushing and grading the processed material through the metal tube was varied by limiting air intake into the fan. Based on preliminary observations the air velocity required for a reasonable separation was 15 to 22 m/s. Air velocity outside this range caused higher loss of bark; air velocity below 15 m/s did not provide enough air flow to push the material through the separation system causing blockage.

The processed material drops into a hopper and is drawn into a 15 cm diameter pipe by a venturi action inside the hopper. The material then enters the discrimination chamber. Inside the chamber, the material falls in two sections based on density. The inner wood due to its higher density drops into the first section of the chamber. The bark and other plant material fall out at the furthest section of the chamber where it exits into the flotation trough. As the air carrying the light material exits the chamber, it creates enough current to push this material it on the top of the water and out of the trough. The bark sinks as soon as it is dropped into the water.

**Figure 11. The separation unit**

**Power source and drive system**

The prototype debarker was powered by a three phase 1.5 kW electrical motor with an output speed of 1420 rpm. The positioning of the drive system was also chosen to allow the use of a tractor PTO drive in the field. It is also possible to convert the drive to a hydraulic system. The speed reduction is arranged by simple and accurate determination of pulley sizes thus avoiding a gear box which is more costly. A variable speed drive motor was used during testing to drive the feed shaft at different settings for experimentation.
Testing and Evaluation of Debarking Machine

The performance evaluation of the debarking machine was carried out in two steps. The first experiment was conducted to test the performance of the bark removal system by evaluating the effect of different feed rates on debarking efficiency and capacity. The second experiment evaluated the performance of the separation system.

Evaluation of the bark removal system

Experimental site and material

The test was conducted in the University of Queensland, Gatton Campus. Guayule shrubs planted in the field in October 2006 were used in the experiment. The average height of the plants was 1m. The plants were harvested manually and transported to the machine. Average temperature of the day was 17.6°C and humidity was 61%.

Experimental design

Debarking performance was evaluated by testing four different feed rates using a variable speed drive motor attached to the feeding mechanism. A completely randomised design was used for the test and each treatment was replicated three times.

Experimental procedure

Guayule shrubs were harvested manually using tree loppers, weighed and placed in bags to avoid drying. Shrubs were fed in to the debarking system by placing each plant on the feed conveyor. Individual plants were fed into the machine for experimental purpose but in normal operation the system allows continuous feeding of the plant material. The conveyor belt speed was kept constant at 24 rpm. A stop watch was used to record time taken from start of feeding until all the material had gone through the debarking system. This data was used to calculate the capacity of the machine.

The machine was switched on for every shrub and the material collected was weighed separately. Samples of 500 g of the processed material were taken after thorough mixing and using the quartering method. The sample was separated into wood, bark, twigs and leaves and analysed. Bark left on wood was manually separated and weighed (Table 2). The quantity of bark removed as well as retained in comparison with the total amount of bark in the sample was used to calculate efficiency of the debarking system.

Table 2. Average mass of shrub and composition of bark, wood and leaf material from 500g processed sample

<table>
<thead>
<tr>
<th>Feed speed (rpm)</th>
<th>Processing Time (s)</th>
<th>Shrub mass (kg)</th>
<th>Bark removed (g)</th>
<th>Bark left (g)</th>
<th>Mass of wood (g)</th>
<th>Total bark (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>58.3</td>
<td>3.5</td>
<td>199.8</td>
<td>9.8</td>
<td>91.0</td>
<td>209.6</td>
</tr>
<tr>
<td>10</td>
<td>23.3</td>
<td>2.8</td>
<td>182.4</td>
<td>12.9</td>
<td>79.9</td>
<td>195.3</td>
</tr>
<tr>
<td>15</td>
<td>23.3</td>
<td>2.9</td>
<td>157.1</td>
<td>24.0</td>
<td>95.4</td>
<td>181.1</td>
</tr>
<tr>
<td>20</td>
<td>28.3</td>
<td>3.1</td>
<td>141.4</td>
<td>16.5</td>
<td>81.9</td>
<td>157.9</td>
</tr>
</tbody>
</table>
The following equations were used to determine the debarking capacity and efficiency.

### Debarking capacity

\[ C = \frac{M}{T} \times 3600 \]  

Where
- \( C \) = Debarking capacity (kg/h)
- \( M \) = Mass of plant material processed (kg)
- \( T \) = Time taken to process each shrub (s)

### Debarking efficiency

\[ E_d = \frac{b_1}{b_1 + b_2} \times 100 \]  

Where
- \( E_d \) = Debarking efficiency (%)
- \( b_1 \) = Mass of bark removed (g)
- \( b_2 \) = Mass of bark left on wood (g)

### Results and discussion

Results of the evaluation of the debarking unit showed that the system can produce a debarking capacity of up to 450 kg/h (Table 3). The capacity ranged from 217.8 to 450.3 kg/h depending on rate of feeding. The variation in capacity was statistically significant at the 5% level and highest capacity was achieved at a feed rate speed of 15 rpm of the feed roller. The lowest feed rate produced the lowest debarking capacity and was significantly different from a feed rate of 15 rpm at 5% level. A feed speed of 10 rpm demonstrated a relatively high efficiency as well as the second highest capacity showing the optimum debarking setting. This capacity may be increased by scaling up the debarking machine to accommodate more than a row of guayule at a time. The highest debarking efficiency (95.1%) was obtained at the lowest feed rate (5rpm) but the differences among different feed rates were not statistically significant. From visual observation of processed material, the majority of the bark that was not removed by the machine was the bark on tiny twigs from new growth, which may contain only a very low quantity of latex.

The percentage of fresh mass of bark ranged from 31-42% and this is slightly higher than what was reported by Kuruvadi et al. (1997). The proportion of bark varied slightly with feed rate but the variations between stem diameters among shrubs may have also contributed to this difference. The percentages of bark, wood and leaf material were consistent among feed rates and shrubs processed and there was no statistical difference.

<table>
<thead>
<tr>
<th>Feed speed (rpm)</th>
<th>Percentage of bark</th>
<th>Percentage of wood</th>
<th>Percentage leaves and twigs</th>
<th>Capacity (kg/h)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>41.9</td>
<td>18.2</td>
<td>39.9</td>
<td>217.8a</td>
<td>95.1</td>
</tr>
<tr>
<td>10</td>
<td>39.0</td>
<td>16.0</td>
<td>45.0</td>
<td>446.0a</td>
<td>93.1</td>
</tr>
<tr>
<td>15</td>
<td>36.2</td>
<td>19.1</td>
<td>44.7</td>
<td>450.3b</td>
<td>85.7</td>
</tr>
<tr>
<td>20</td>
<td>31.6</td>
<td>16.4</td>
<td>52.0</td>
<td>376.9a</td>
<td>88.7</td>
</tr>
</tbody>
</table>
Evaluation of the separation system

Experimental site and material

The test was conducted in the University of Queensland at Gatton campus. Guayule shrubs planted in the field in October 2006 were used in the experiment. The average height of the plants was 1 m. The plants were harvested manually and taken to the machine. Average temperature of the day was 17.7 °C and humidity was 76%.

Experimental design

The separation system was evaluated by testing four different air velocity settings: 15, 18, 20, and 22 m/s. This variable was chosen based on preliminary testing in which variation in air velocity showed different separation outcomes. A completely randomised design was used for arrangement of unprocessed guayule shrubs and each treatment was replicated three times.

Experimental procedure

Harvested shrubs were weighed and placed in bags to avoid drying. Shrubs were fed in to the debarking system by placing each plant on the feed conveyor. Feed rate was set at 10 rpm of the feeder, which provided higher capacity without affecting debarking efficiency, based on debarking test results. The machine was switched on for every shrub and the material collected was weighed separately. The separation system places the wood at the back of the unit and the bark and leaves are pushed into a current of water where the twigs and leaves float away and the bark sinks in the water. The bark was removed by draining the water and oven drying the separated material at 60 °C for 85 hours to obtain dry matter weight for comparison. Any bark lost together with the leaf material and with the wood was manually separated after drying. Efficiency of bark separation was determined using the dry matter weight of these three portions of the bark. Efficiency of separation of wood was also computed by using mass of wood at each three collection points. The following formulas were used to calculate the efficiencies.

Bark separation efficiency

\[
E_b = \frac{m_1}{m_1 + m_2 + m_3} \times 100
\]

Where

- \( E_b \) = Bark separation efficiency (%)
- \( m_1 \) = Mass of bark lost with wood (g)
- \( m_2 \) = Mass of bark left on wood (g)
- \( m_3 \) = Mass of bark lost with leaf material (g)

Wood separation efficiency

\[
E_w = \frac{w_1}{w_1 + w_2} \times 100
\]

Where

- \( E_w \) = Wood separation efficiency (%)
- \( w_1 \) = Mass of wood separated (g)
- \( w_2 \) = Mass of wood in the bark portion (g)
Results and discussion

The separation system produced a maximum bark separation efficiency of 74.8 % at air velocity of 22 m/s (Table 4). However, the differences in bark separation efficiency among different air velocities were not statistically significant at the 5% level. The possible reason for highest efficiency at 22 m/s was that the air speed was strong enough to blow more bark towards the front section resulting in less bark material at the back of the discrimination chamber where inner wood material is collected. On the other hand, at this velocity the wood separation efficiency was minimum (48.3%) due to some smaller stem pieces pushed forward to the bark collection point by higher air velocity. This result has indicated the need for fine tuning of air velocity between 20 and 22 m/s. Most of the inefficiencies were results of bark being removed with wood (Table 5) which demonstrates the need to further investigate on air velocity and cut-off distances in the discrimination chamber. The percentages of bark in the wood collection section and in the leaves, varied slightly but the differences were not statistically significant. The majority of bark collected from the leaf collection point was the outer skin (epidermis) of the stem which may contain only little quantity of latex.

Figure 12. Samples of bark, wood and leaves separated

The average dry mass of shrubs varied between 834.6 and 1713.8 and this variation is due to the different sizes of guayule shrubs collected from the field. Percentages of bark, wood and leaves, for each plant, were consistent at different air velocities and the differences were not statistically significant at 5% level.
### Table 4. Average separation efficiencies, dry mass and percentage of material

<table>
<thead>
<tr>
<th>Air Velocity (m/s)</th>
<th>Dry mass of material/shrub (g)</th>
<th>Percentage of bark (%)</th>
<th>Percentage of wood (%)</th>
<th>Percentage of leaves (%)</th>
<th>Bark separation efficiency (%)</th>
<th>Wood separation efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>834.6</td>
<td>21.2</td>
<td>53.9</td>
<td>24.9</td>
<td>62.4</td>
<td>79.4a</td>
</tr>
<tr>
<td>18</td>
<td>1089.1</td>
<td>23.1</td>
<td>53.8</td>
<td>23.1</td>
<td>62.7</td>
<td>82.9a</td>
</tr>
<tr>
<td>20</td>
<td>1713.8</td>
<td>20.1</td>
<td>52.4</td>
<td>27.5</td>
<td>63.6</td>
<td>83.7a</td>
</tr>
<tr>
<td>22</td>
<td>1073.4</td>
<td>20.9</td>
<td>51.7</td>
<td>27.4</td>
<td>74.8</td>
<td>48.3b</td>
</tr>
</tbody>
</table>

### Table 5. Average percentage of bark in leaf section and wood section

<table>
<thead>
<tr>
<th>Air Velocity (m/s)</th>
<th>Percentage bark in wood (%)</th>
<th>Percentages of bark in leaves (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>21.42</td>
<td>5.84</td>
</tr>
<tr>
<td>18</td>
<td>23.24</td>
<td>3.74</td>
</tr>
<tr>
<td>20</td>
<td>21.98</td>
<td>4.72</td>
</tr>
<tr>
<td>22</td>
<td>16.13</td>
<td>3.79</td>
</tr>
</tbody>
</table>
Implications and Recommendations

Bark removal and separation from a shrub with multiple stems of varying diameter is an extremely challenging undertaking. However, the outcome from the development and evaluation of the debarking machine has demonstrated a promising result with huge potential in the commercialization of guayule. The prototype can easily be scaled up to a fully commercial machine. Further modifications of drive systems with a single power source such as tractor hydraulic system are also essential for ease of utilization in the field.

This project did not include the harvest mechanization of the operation but a harvesting system has been developed in the US (Coates, 1990). Therefore, provision needs to be made for attachment of a shrub harvester to the debarking machine to complete the field operation. Some improvements in the feeding system can be made on the conveyor belt that drags individual shrubs towards the feed section by lowering the speed to match the feed rate and also to prevent twisting of shrub when branches are caught by the feed roller. There is a potential to improve the separation efficiency by fine tuning the air velocity and minor modifications on the venturi system, and the flotation unit to facilitate free flow of material without blockage. It is also important to investigate the bark processed in terms of quality of latex. In addition, the economic feasibility needs to be studied.

Overall this study has demonstrated that it is possible to significantly reduce the cost of transporting whole guayule shrub and increase the throughput capacity of a latex extraction plant by retaining 60–70% of plant material in the field. Further work on up scaling the prototype debarking system to a commercial field machine will greatly benefit the guayule industry.
References


Improving Latex Extraction Technology by Debarking Guayule

By M.L. Gupta, D.L. George and G.M. Bedane
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