EXTRACTION AND CHARACTERIZATION OF LATEX FROM THE EUPHORBIA CANDELABRUM PLANT

C. Bess¹*, J. Mibei¹

¹. The Technical University of Kenya. P.O. Box 52428,00200 Nairobi-Kenya.

DOI: https://doi.org/10.37017/jeae-volume8-no1.2022-3
Publication Date: 14 January 2022

ABSTRACT:
For decades, the main source for natural rubber has been the Hevea brasiliensis plant, which represents raw material for approximately 40% of the elastomeric market. In recent years, the supply of natural rubber has been declining due in part to fungal disease eradicating the Hevea brasiliensis tree as well as effects of climate change. To this end, other sources are being explored for the presence of the biopolymer poly(cis-1,4-isoprene), a major component in natural rubber. Latex was collected by incising the stem of Euphorbia Candelabrum plant, from which natural rubber was extracted using hexane and acetone solvent. The extracted latex samples were found per weight percent volume to contain on average 13% rubber, 7.92% resin, and 1.8% gel. The rubber hydrocarbon was characterized using GC-MS and FTIR analysis. FTIR analysis showed peaks at 935 cm⁻¹, 1290 cm⁻¹, 1457 cm⁻¹, 1705 cm⁻¹, and 29647 cm⁻¹. GC-MS analysis showed a mass-spectra with peaks with a ratio of charge number of ions similar to that of pure isoprene. Correlativity between literature data and laboratory analysis was conducted, yielding a R-squared value of 0.786.

Keywords: Natural rubber, latex, Euphorbia Candelabrum

1.0 INTRODUCTION
Natural rubber (cis-1,4-polyisoprene), an elastic material produced from latex sap, the milky exudate from tropical rubber trees, is an addition polymer of the basic monomer isoprene - 2- methylbuta-1, 3-diene - (C5H8)n. Used in more than 40,000 products, including more than 400 medical devices as well as
airplane tires, baby pacifiers and toys, natural rubber is one of the more important polymers produced by plants. Approximately 90% of the world's natural rubber is obtained from the latex from the Hevea Brasiliensis tree, with production of the rubber occurring predominantly in the central parts of Asia (Bangkok, 2011). Native to the Amazon region, the Hevea Brasiliensis plant was introduced to the Far East in the late eighteenth century, resulting in the major producers of rubber being Thailand, Indonesia, Malaysia, India, China, Vietnam and Sri Lanka (Bangkok, 2011) (Figure 1). On average, these countries combined, accounted for approximately 85% of the world's natural rubber production (Bangkok, 2011). In 2020, with a production of some 4.5 million tonnes, Thailand continued to be the largest producer of natural rubber, followed by Indonesia with 2.9 tonnes (Association of Natural Rubber producing Countries).

Over the last few decades, production of natural rubber from the Hevea Brasiliensis plant has been declining as the plant has been under threat due to:

i. **Disease risk** - the fungal disease South American Leaf Blight (SALB) caused by Microcyclus ulei, has inhibited natural rubber production on a commercial scale and pose a direct threat to the natural rubber industry in the Far East region. To date, the use of modern systemic fungicides and improved application techniques have failed to prevent large losses and dieback of the rubber plant.

ii. **Location-specific** - conditions necessary for the growth of the Hevea Brasiliensis rubber trees are location specific and currently its growth occur mainly in the Far East.

iii. **Competition with other products**: the fast-growing market for seemingly more lucrative products such as palm oil has resulted in less acreage being dedicated to the planting of trees for the production of natural rubber. Beilen (2006) reported that the palm oil acreage in Malaysia increased in only three decades from less than 100,000 hectares to almost 2,000,000 hectares, which is significantly more than the rubber acreage.

Reduced production of natural rubber has been observed in the last few years, due in part, to economics as well as the impact of the COVID pandemic on supply chains. Despite a surge in demand for natural rubber products such as latex gloves, the volatile nature of the rubber market has resulted in a decline in price of the product at the start of the pandemic (Figure 2). A cash crop in many of the producing countries, smallholders are looking to diversify their income stream; this is due to the climate change impact as well as the afore mentioned leaf disease as well as little incentive to plant new trees (which takes on average seven years to mature), making the supply of natural rubber to be under threat.
The above-mentioned factors have intensified the search for alternative sources of rubber. In the 1940s, alternative perennial rubber-bearing plants native to the mountains of Kazakhstan and Uzbekistan such as Scorzonera tau-saghyz and Scorzonera Uzbekistanica as well as the Taraxacum kok-saghyz plant commonly known as Russian dandelion were discovered and began being industrially cultivated in a bid to gain independence from foreign sources. During the same period, the
use of *Parthenium argentatum*, commonly known as guayule, native to the rangeland area of the Chihuahuan Desert; the southwestern United States and northern Mexico was explored.

On the African continent, Ivory Coast is the leading producer of natural rubber, which is produced from the *Hevea brasiliensis* plant. However, the search for other potential plant species not susceptible to SALB is being pursued. To this end, the potential of the *Euphorbia Candelabrum* plant commonly known as the candelabra tree or tree euphorbia or in Swahili as the Mtungutungii plant, which is found extensively across East Africa is being explored. The *Euphorbia Candelabrum* tree is used extensively in semi-arid regions of Kenya for fencing as well as for its aesthetic value, often being used as an ornamental plant. A xerophyte, the ease of propagation of *Euphorbia Candelabrum* provides its strategic advantage. Khan and Akhtar (2006) showed that the *Euphorbia Caducifolia*, from the Euphorbiaceae family as the *Euphorbia Candelabrum*, contained the rubber hydrocarbon cis-1,4 polyisoprene.

Euphorbias range from annual weed to trees and can be found on dry and rocky landscapes. There are more than 1500 species of Euphorbias in the world, with the *Euphorbia Candelabrum* species being found extensively in eastern Africa. Characterized by the presence of white milky latex that exudes upon tapping, the rubber in the *Euphorbia Candelabrum* is contained in the latex vessels or tubes which presents a strategic advantage in harvesting the rubber since the stem of the *Euphorbia Candelabrum* plant is ruptured by cutting into the plant and simply collecting the latex in comparison with the guayule plant, where the rubber is contained in individual plant cells of the plant. (Marina & Van Dijk, 2019). Also, the *Hevea Brasiliensis* and the *Euphorbia Candelabrum* are from the same family, presenting a clear hypothesis that *Euphorbia Candelabrum* might be a source for natural rubber.

### 2.0 MATERIALS AND METHODS

#### 2.1 SAMPLE COLLECTION AND PREPARATION

Two sets of latex samples were collected from the *Euphorbia Candelabrum* plant during the period September to October, the dry season. Collection was done during this period to ensure a minimal water content of the latex.

The latex was extracted and collected in a clean, dry glass container and immediately enclosed to prevent contact with water vapor and therefore degradation of the sample. The latex was then filtered to remove solid particles, and the weight measurements taken before exposing the latex to the air to coagulate.

#### 2.2 CHARACTERIZATION OF LATEX USING GAS CHROMATOGRAPHY-MASS SPECTROMETRY (GCMS)

Characterization of the latex was carried out using gas chromatography-mass spectrometry. The identification of the latex constituent was carried out using a QP2010 gas chromatography with Thermal Desorption System, TD 20 coupled with Mass Spectroscopy. The ionization voltage was 70eV. Gas Chromatography was conducted in the temperature programming mode with a Restek column (0.25 mm, 60 m, XTI-5). The initial column temperature was 50°C for 1 minute and then increased linearly to 300 °C with a ramp rate of 5°C. The temperature of the injection port was 200°C, and the GC-MS interface was maintained at 250°C. The sample was introduced through an all-glass injector working in a split mode, with a helium carrier gas flow rate of 0.93ml min-1. The identification of compounds was accomplished by
comparison of retention time and fragmentation pattern and mass spectra of the GC-MS.

2.3. SOLVENT EXTRACTION OF NATURAL RUBBER

Solvent extraction was achieved by using a Soxhlet extractor. To obtain different extracts for analysis, the extracting solvent was varied, whereby hexane and acetone were used as the extracting solvents. Hexane is used because it has a high evaporation rate and low boiling point. Acetone was selected due to its low boiling point of 56 0C and its ability to dissolve both polar and non-polar substances. Also, Beilen (2006), showed that acetone is able to dissolve the resin present in natural rubber. The extracts were concentrated using a rotary evaporator. The extract was then weighed after the extraction.

The resin content in the latex was determined by taking a pre-measured mass of the dried sample and dissolving it in 2 mL acetone. The mixture was then centrifuged at 12,000 rpm for 30 minutes. The acetone extract was then transferred into pre-weighed vials and evaporated under vacuum at 65 0C using a speed-vac centrifugal concentrator. The mass of the residual dried material, which is the resin, was determined by re-weighing the vials. The resin content was then calculated with respect to the mass of the sample.

The rubber’s gel content was determined by taking a predetermined mass of the dried sample and soaking it in toluene for 24 hours. The resulting solution was then filtered through a 120-micrometer nylon net filter disc. The amount of gel was determined by drying and weighing the residue.

2.4. ANALYSIS OF NATURAL RUBBER EXTRACT

Analysis of the chemical and physical properties of the latex extracted from the Euphorbia Candelabrum plant was carried out using Fourier Transform Infrared (FTIR) analysis. The extract was first tested using a standard polystyrene to check the functionality of the machine. The potassium bromide plates are first cleaned using acetone. A drop of the sample extract is then cast between the two potassium bromide plates to make a thin film. The FTIR spectra are then collected in the region 400 cm⁻¹ to 4000 cm⁻¹. At a resolution of 4 cm⁻¹, 6 number of scans, and a velocity of 7.5 kHz.

3.0 RESULTS AND DISCUSSION

3.1 EXTRACTION OF RUBBER

Rubber was extracted from the latex samples using (i) hexane and (ii) acetone as solvent. The mass of rubber for the respective solvent is shown at Table 1, indicating that extraction using hexane solvent was slightly higher than that of acetone. Qualitative analysis in the subsequent steps focused solely on the hexane extract.

Table 1: Solvent extraction of rubber using Hexane and (ii) Acetone as solvent

| SOLVENT       | HEXANE | ACETONE |
|---------------|--------|---------|
|               | Sample 1 | Sample 2 | Sample 1 | Sample 2 |
| Mass of rubber/g | 12.86   | 13.76   | 11.83   | 12.93   |
| Average mass of rubber/g | 13.31   |         |         |         |
| Average w/v%  | 13.31   |         |         |         |
The solvent extract from hexane solvent extraction was quantitatively analyzed to determine the amount of rubber, water, gel, resin and contaminants. The amount of gel present is an indicator of natural rubber quality. The average composition of the latex is shown at Table 2. The rubber yield of 13.3 % from *Euphorbia Candelabrum* latex using hexane extract compares favorably with other alternative sources prompted by other researchers (Figure 4).

### Table 2: *E. Candelabrum*: - Hexane Extract Components % Composition

| Mass (g)     | Run 1 | Run 2 | Average | %  |
|--------------|-------|-------|---------|----|
| Latex (100ml)| 50.00 | 50.00 |         |    |
| Dried latex  | 14.75 | 16.25 | 15.50   |    |
| Water        | 35.29 | 33.71 | 34.50   | 69 |
### Table 3: Mass (g) Composition

|        | Run 1 | Run 2 | Average | %   |
|--------|-------|-------|---------|-----|
| Rubber | 12.86 | 13.76 | 13.31   | 13  |
| Gel    | 0.2448| 0.2344| 0.2396  | 1.8 |
| Resin  | 3.95  | 3.97  | 3.96    | 7.9 |
| Contaminants | 3.33 | 3.37 | 3.35 | 6.7 |

---

**Figure 4:** Comparison of Natural Rubber content for the primary source of rubber and alternative sources of natural rubber Source: Vaysse et al. 2012; Taurines et al., 2019

### 3.2. GC-MS Analysis

The GC-MS chromatogram of *Euphorbia Candelabrum* latex samples revealed 25 peaks indicating the presence of 25 different biochemicals, which were determined by comparing their peak area percentage, retention indices, and mass spectra fragmentation pattern with those in the National Institute of Standards and Technology (NIST) database. Some suggested compounds from the GC-MS Chromatogram are in Table 3.

The GC-MS chromatogram and the mass spectra of the *Euphorbia Candelabrum* extract indicate a similarity with that of isoprene, main chemical component of natural rubber, obtained from literature at; Peak 15, Peak 16, Peak 17, Peak 18, Peak 19, and Peak 20.

To ascertain the presence of isoprene molecules, correlativity between the data from the standard and that from the *E. Candelabrum* extract is established. This shows a strong correlation between isoprene data obtained from literature with the results from the GC-MS analysis of the *Euphorbia Candelabrum* extract. The R-Squared value of 0.7865 is an indicator of a strong correlation. Therefore, it was concluded that isoprene molecules are present in the *E. Candelabrum* latex extract subject to further proof through other analytical methods.
The GC-MS analysis was conducted to determine the presence isoprene, the main component in natural rubber. The isoprene spectrum obtained from published literature (Figure 6) shows isoprene peaks with its relative abundance. The GC-MS chromatogram and the mass spectra of the *Euphorbia Candelabrum* extract, indicate a similarity with that of isoprene obtained at Peak 15, Peak 16, Peak 17, Peak 18, Peak 19 and Peak 20. The **R-Squared** value of 0.7865 (Figure 7) is an indicator of a strong correlation between literature data and the analysis undertaken.

![Figure 5: GC-MS Chromatogram](image)

**Table 3: Suggested Compounds from the GC-MS Chromatogram**

| Peak | R. Time | Area    | Peak Area | Possible compound          |
|------|---------|---------|-----------|---------------------------|
| 1    | 3.485   | 71023   | 2.22      | Toluene                   |
| 2    | 3.775   | 23659   | 0.74      | Octane                    |
| 3    | 5.061   | 412190  | 12.88     | Ethylbenzene              |
| 4    | 5.250   | 201446  | 6.29      | o-Xylene                  |
| 5    | 5.653   | 68100   | 2.13      | Nonane                    |
| 6    | 5.763   | 149058  | 4.66      | o-Xylene                  |
| 7    | 7.608   | 47104   | 1.47      | Benzene,                  |
| 8    | 8.140   | 171597  | 5.36      | Decane                    |
| 9    | 8.295   | 47233   | 1.48      | Benzene,                  |
| 10   | 8.704   | 41088   | 1.28      | Decane, 4-methyl-         |
| 11   | 9.074   | 30854   | 0.96      | Benzene, 1,2,4-trimethyl  |
| 12   | 9.183   | 239655  | 7.49      | D-Limonene                |
| 13   | 10.960  | 146170  | 4.57      | Undecane                  |
| Peak | R. Time  | Area    | Peak Area | Possible compound                                                                 |
|------|----------|---------|-----------|-----------------------------------------------------------------------------------|
| 14   | 13.847   | 33239   | 1.04      | Dodecane                                                                         |
| 15   | 18.951   | 349322  | 10.91     | 2H-2,4a-Methanonaphthalene,                                                        |
| 16   | 29.109   | 74660   | 2.33      | Cycloheptane, 4-methylene-1-methyl-2-(2-methyl-1-propen-1-yl)-1-vinyl...           |
| 17   | 32.068   | 69368   | 2.17      | geranyl- Alpha. -terpinene                                                          |
| 18   | 32.780   | 45802   | 1.43      | Cycloheptane, 4-methylene-1-methyl-2-(2-methyl-1-propen-1-yl)-1-vinyl...           |
| 19   | 39.613   | 36846   | 1.15      | Cyclononasiloxane, octadecamethyl-                                                |
| 20   | 40.910   | 73005   | 2.28      | Heptacos-1-ene                                                                    |
| 21   | 43.936   | 396898  | 12.40     | Heptacos-1-ene                                                                    |
| 22   | 44.257   | 161960  | 5.06      | 2-methyloctacosane                                                                |
| 23   | 45.844   | 64635   | 2.02      | 9-Octadecenamide,                                                                 |
| 24   | 45.926   | 201584  | 6.30      | Squalene                                                                          |
| 25   | 46.744   | 44941   | 1.40      | Nonacos-1-ene                                                                     |

**Figure 6: Pure Isoprene Spectrum** Source: Mass Bank of North America (ucdavis.edu)

**Table 4: Pure Isoprene Data for Abundance and M/Z obtained from figure 6.**
Table 5: Data for Abundance and M/Z for the E. Candelabrum Hexane Extract

| Ratio of mass to charge number of ions (m/z) | Abundance |
|---------------------------------------------|-----------|
| 119.05 (Peak 15)                            | 10.91     |
| 107.1 (Peak 16)                             | 2.33      |
| 69.1 (Peak 17)                              | 2.17      |
| 107.1 (Peak 18)                             | 1.43      |
| 73.1 (Peak 19)                              | 1.15      |
| 55.05 (Peak 20)                             | 2.28      |

Figure 7: Correlation of Isoprene data from literature and E. Candelabrum Extract data.
3.3. FTIR ANALYSIS

The results for the absorbance and the transmittance spectrum from the FTIR analysis are illustrated in Figure 8 and Figure 9. Analysis of the data involved identifying the different functional groups in different spectra. The presence of cis-1,4 polyisoprene, which is the functional group in natural rubber, is ascertained by comparing the FTIR Spectrum with published literature on natural rubber.

The FTIR spectra showed distinct high peaks at wavenumbers 464.28 cm\(^{-1}\), 935.26 cm\(^{-1}\), 1290.04 cm\(^{-1}\), 1456.77 cm\(^{-1}\), 1705.30 cm\(^{-1}\), and 2964.68 cm\(^{-1}\). Based on literature data the following characteristics are observed:

(i) C-H stretching corresponding to a characteristic absorption of 3100-2800 cm\(^{-1}\),

(ii) C=C stretching corresponding to a characteristic absorption of 1680-1620 cm\(^{-1}\)

(iii) C-H bending absorption characteristic which occurs at 860-680 cm\(^{-1}\) and

(iv) C=C bending absorption characteristic which occurs at 1700-1500 cm\(^{-1}\).

Based on the literature, it can be concluded that the FTIR Spectrum is characteristic of cis-1,4 polyisoprene 1664 and 835 cm\(^{-1}\), with the lower peaks due to C-H bending and the higher peaks due to C=C stretching (Spanò et al., 2012)

![FTIR Absorbance Spectra](image)

*Figure 8: FTIR Absorbance Spectra.*
Rubber monoculture and diversification of natural rubber use and investment have resulted in environmental and social issues. Between 2003 and 2014, the rubber industry cleared 75,000km² of tropical forests (Mighty Earth, 2019), which were biodiversity hotspots and the habitats of numerous endangered species, including tigers and elephants. Therefore, it is essential for natural rubber producers to raise their awareness and management capacity of investment and sustainable development, thereby engaging in practices to mitigate against adverse social, environmental, and economic impacts. Identifying other viable sources of natural rubber, is a strategy which can be employed to not only contribute to the sustainability and environmental factors, but also providing an economic platform.

Analysis of the latex extracted from the stem of Euphorbia Candelabrum plant had a composition of water, gel and resin being 69%, 1.8%, 7.92% respectively. The rubber hydrocarbon was characterized using GC-MS analysis which showed a high correlation for the presence of isoprene compounds in the 25 different peaks of the Euphorbia Candelabrum latex. The functional group of natural rubber, cis-1,4-polyisoprene, was ascertained through FTIR analysis. The analysis showed that the Euphorbia Candelabrum plant contains on average 13w/v% natural rubber, almost double that obtained from the Parthenium argentatum plant, from which bio-rubber is currently being produced. Rubber from the Euphorbia Candelabrum plant can present an alternative raw material source which might address environmental aspects and meets the demand for natural rubber.

Further research can focus on the purification mechanisms after solvent extraction and properties of the rubber which can be made from the extract from the Euphorbia Candelabrum plant, as well as the viability of large-scale production.

**Figure 9: FTIR Transmittance Spectra**

4.0 CONCLUSION

Rubber monoculture and diversification of natural rubber use and investment have resulted in environmental and social issues. Between 2003 and 2014, the rubber industry cleared 75,000km² of tropical forests (Mighty Earth, 2019), which were biodiversity hotspots and the habitats of numerous endangered species, including tigers and elephants. Therefore, it is essential for natural rubber producers to raise their awareness and management capacity of investment and sustainable development, thereby engaging in practices to mitigate against adverse social, environmental, and economic impacts. Identifying other viable sources of natural rubber, is a strategy which can be employed to not only contribute to the sustainability and environmental factors, but also providing an economic platform.

Analysis of the latex extracted from the stem of Euphorbia Candelabrum plant had a composition of water, gel and resin being 69%, 1.8%, 7.92% respectively. The rubber hydrocarbon was characterized using GC-MS analysis which showed a high correlation for the presence of isoprene compounds in the 25 different peaks of the Euphorbia Candelabrum latex. The functional group of natural rubber, cis-1,4-polyisoprene, was ascertained through FTIR analysis. The analysis showed that the Euphorbia Candelabrum plant contains on average 13w/v% natural rubber, almost double that obtained from the Parthenium argentatum plant, from which bio-rubber is currently being produced. Rubber from the Euphorbia Candelabrum plant can present an alternative raw material source which might address environmental aspects and meets the demand for natural rubber.

Further research can focus on the purification mechanisms after solvent extraction and properties of the rubber which can be made from the extract from the Euphorbia Candelabrum plant, as well as the viability of large-scale production.
REFERENCES

Bridgestone, & “The PENRA Story,” The Ohio State University. (2012, July 6). Tire Manufacturer Testing Dandelion Rubber. Retrieved from https://www.polymernews.com/blog/tire-manufacturer-testing-rubber-from-dandelion

Cambridge Isotope Laboratories, & UCLA Department of Chemistry and Biochemistry. (n.d.). IR absorption table. WebSpectra - Problems in NMR and IR Spectroscopy. https://webspectra.chem.ucla.edu//irtable.html

China Chamber of Commerce of Metals, Minerals & Chemicals Importers & Exporte. (2017). Guidance for Sustainable Natural Rubber. Retrieved from https://www.followingthemoney.org/wp-content/uploads/2019/02/2017_CCCMC_Guidance-for-Sustainable-Natural-Rubber_E.pdf

Chris Woodford. (2019, July 26). Rubber: A simple introduction. Retrieved from https://www.explainthatstuff.com/rubber.html

Claudia Mascia, Delia Spano, Francesca Pintus, Mariano Andrea, Mariano Casu, Giovanni Floris, & Rosaria Medda. (2012). Extraction and Characterization of a natural rubber from Euphorbia characias latex. Biopolymers, 97(8). Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1002/bi b.22044

Consolacion, Y. R., & Kimberly, B. C. (2014). Triterpenes from Euphorbia hirta and their cytotoxicity. Chinese Journal of Natural Medicines, 11(5), 528-533. doi:10.3724/sp.j.1009.2013.00528

Cornish, K. (2001) Similarities and differences in rubber biochemistry among plant species. Phytochemistry 57, 1123-1134.

Cornish, K., and Schloman, W.W. (2005) Rubber, guayule. In Encyclopedia of Polymer Science and Technology, J.I. Kroschwitz, ed (Hoboken: Wiley Interscience), pp. 670-698.

Cornish, K., Martin, J.A., Marentis, R.T., and Plamthottam, S. (2006a) Extraction and fractionation of biopolymers and resins from plant materials. US Patent 2006/0106183

Cornish, K., McMahan, C.M., Pearson, C.H., Ray, D.T., and Shintani, D.K. (2005) Biotechnological development of domestic rubber producing crops. In Technical Meeting of the Rubber Division, American Chemical Society (San Antonio).

Cornish, K., McCoy, R.G., Martin, J.A., Williams, J., and Nocera, A. (2006b) Biopolymer extraction from plant materials. US Patent 2006/0149015

Cornish, K., Brichta, J.L., Yu, P., Wood, D.F., McGlothlin, M.W., and Martin, J.A. (2001) guayule latex provides a solution for the critical demands of the non allergenic medical products market. Agro Food Industry Hi-Tech 12, 27-31.

Ecolink. (2020, May 21). Why is hexane used for extraction? - Buy hexane online. Industrial Degreasers | Organic Solvents | Parts Washers. https://ecolink.com/info/why-is-hexane-used-for-extraction/

Ecolink. (2020, May 21). Why is acetone a good solvent? - Acetone solvent cleaners. Industrial Degreasers | Organic Solvents | Parts Washers. https://ecolink.com/info/why-is-acetone-a-good-solvent/

Cornish, K. (2014). Biosynthesis of natural rubber (NR) in different rubber-producing species. Chemistry, Manufacture and Applications of Natural Rubber, 3-29. doi:10.1533/9780857096913.1.3

Guayule: An Alternative Source of Natural Rubber: Report of an Ad Hoc Panel of the Board of Agriculture and Renewable Resources, Commission on Natural Resources, and Advisory Committee on Technology Innovation, Board on Science and Technology for International Development, Commission on International Relations. (1977). Washington, DC: National Academies.

Heba Soffar. (2019, October 8). Dangers and bad effects of burning plastics and rubber on humans and global warming. Retrieved from https://www.online-sciences.com/health/dangers-
and-bad effects-of-burning-plastics-and-rubber-on-humans-and-global-warming/

Hunseung Kang, Min Young Kang, & Kyung-Hwan Han2. (2000, July). Identification of Natural Rubber and Characterization of Rubber Biosynthetic Activity in Fig Tree. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC59076/

James Ashenhurst. (2019, August 21). Polar Protic? Polar Aprotic? Nonpolar? All About Solvents – Master Organic Chemistry. Retrieved from https://www.masterorganicchemistry.com/2012/04/27/polar-protic-polar-aprotic-nonpolar-

The Encyclopedia of Succulents. (n.d.). Euphorbia ingens. LLIFLE. https://www.llifle.com/Encyclopedia/SUCCULENTS/Family/Euphorbiaceae/27231/Euphorbia_ingens

The Hygenic Corporation. (2012, March 20). The differences between "latex" and "natural rubber". Retrieved from http://www.hygenic.com/news/the-differences-between-latex-and-natural-

Katrina Cornish, & Hans Mooibroek. (2000, April 1). (PDF) Alternative sources of natural rubber. Retrieved from https://www.researchgate.net/publication/12513699_Alternative_sources_of_natural_rubber Khan, Rasheed A & Akhtar. (2003). Latexes from Euphorbia Caducifolia – Isolation and Characterisation of Rubber Hydrocarbon. Part-I. Pak. J. Sci. Ind 46(5) 311 - 316

Mali, P. Y., & Panchal, S. S. (2017). Euphorbia nerifolia L.: Review on botany, ethnomedicinal uses, phytochemistry and biological activities. Asian Pacific Journal of Tropical Medicine, 10(5), 430-438. doi: 10.1016/j.apjtm.2017.05.003

Marina Arias, & Peter J. Van Dijk. (2019, July 19). What Is Natural Rubber and Why Are We Searching for New Sources? Retrieved from https://kids.frontiersin.org/article/10.3389/frnym.2019.00100 Michelle Labbe. (2017, April 12). Properties of Natural & Synthetic Rubber. Retrieved from https://sciencing.com/properties-natural-synthetic-rubber-7686133.html

Mighty Earth. (2019, July 2). Five reasons why your company should be using sustainable natural rubber. Retrieved from http://www.mightyearth.org/five-reasons-why-your-company-should-be-using-sustainable-natural-rubber/

Mooibroek, H., & Cornish, K. (2000). Alternative sources of natural rubber. Applied Microbiology and Biotechnology, 53(4), 355-365. Doi: 10.1007/s002530051627

Ragasa, C. Y., & Cornelio, K. B. (2013). Triterpenes from Euphorbia hirta and their cytotoxicity. Chinese Journal of Natural Medicines, 11(5), 528-533. doi:10.1016/s1875-5364(13)60096-5

Rich Renehan. (2016, June 7). How to Choose between Natural Rubber Latex (NR), Nitrile (NBR), and Vinyl (PVC) Gloves? Retrieved from https://www.linkedin.com/pulse/how-choose-between-natural-rubber-latex-nr-nitrile-nbr-rich-ren

Sayyed Nazim, Shaikh Arshad, Shaikh Siraj, & Patel M Siddik. (2011, April 1). (PDF) EUPHORBIA NERIFOLIA LINN: A PHYTOPHARMACOLOGICAL REVIEW. Retrieved from https://www.researchgate.net/publication/228456016_EUPHORBIA_NERIFOLIA_LINN_A_PHYTOPHARMACOLOGICAL_REVIEW

Shaaban, M., Ali, M., Tala, M. F., Hamed, A., & Hassan, A. Z. (2018). Ecological and Phytochemical Studies on Euphorbia retusa (Forssk.) from Egyptian Habitat. Journal of Analytical Methods in Chemistry, 2018, 1-10. doi:10.1155/2018/9143683

Soratana, K., Rasutis, D., Azarabadi, H., Eranki, P. L., & Landis, A. E. (2017). Guayule as an alternative source of natural rubber: A comparative life cycle assessment with Hevea and synthetic rubber Journal of Cleaner Production, 59, 271-280.doi: 10.1016/j.jclepro.2017.05.070

Spanò, D., Pintus, F., Mascia, C., Scorciapino, M. A., Casu, M., Floris, G., & Medda, R. (2012).
Extraction and characterization of a natural rubber from euphorbia characias LaTeX.

**Biopolymers, 97**(8), 589-594.  
https://doi.org/10.1002/bip.22044

Vaysee, L., Bonfils F., Sainte-Beuve, J. & Cartault M. (2012). Natural Rubber. Polymer Science: A Comprehensive Reference, Elsevier, 2012, 281-293

Thorat, B. R. (2017). Review on Euphorbia neriifolia Plant. Biomedical Journal of Scientific & Technical Research, 1(6). doi:10.26717/bjstr.2017.01.000523

Van Beilen, J. B., & Poirier, Y. (2007). Establishment of new crops for the production of natural rubber. Trends in Biotechnology, 25(11), 522-529. doi:10.1016/j.tibtech.2007.08.009

Van Beilen, J. B., & Poirier, Y. (2007). Guayule and Russian Dandelion as Alternative Sources of Natural Rubber. Critical Reviews in Biotechnology, 27(4), 217-231. doi:10.1080/07388550701775927