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Tree-borne Oilseed Crops: *Jatropha curcas, Ricinus communis*, *Anacardium occidentale* and Some Native Trees for Oil Production for Bio-energy Source in Papua New Guinea

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Abstract

A heavy dependence on non-renewable fossil fuel as energy source by industries is contributing to environmental degradation due to emission of toxic gases particularly carbon. This has become a global concern and an interest has aroused in finding an alternative energy source from organic biomasses to produce bio-energy whilst at the same time provides solution to lessen environmental degradation. Crude oil derivatives from tree-borne oilseed (TBO) plants are likely bio-energy source to replace fossil fuel products. Additionally, agroforestry biomasses/residues are alternative feedstock to source bio-energy. This paper discussed the three TBO crops (*Jatropha curcas, Ricinus communis* and *Anacardium occidentale*) and their potential to yield oils for biofuel production to source energy and possibility of commercial cultivation in Papua New Guinea (PNG). Since introduction by early European settlers, these crops naturalized well in PNG environmental conditions where they have promising growth performances and produce crude oils from their seed kernels. Presently, their oil extraction and utilization is not commercially known in PNG but limited to local use only. Also, this paper highlighted commercially grown crops for crude oil production and native TBO trees. Further, it is suggested that TBO trees have huge potential and such plants could be adopted as planting stocks for intercropping in agroforestry practices.

Keywords: *Jatropha curcas*, *Anacardium occidentale, Ricinus communis,* tree-borne oilseed plants, crude oil production, essential oil, bio-energy, agroforestry practice.

1. Introduction

Global population explosion, high economic growth and industrialization lead to increased demand for fossil fuels as energy source (Harisudan et. al., 2011). A heavy reliance on fossil fuels is now becoming a global concern due to emission of toxic gas (carbon) which causes fatal environmental degradation e.g. depletion of ozone layer and warming of earth's surface. As a result, there is a renewed interest in sourcing alternative energy and a focus is now on renewable bio-energy that will have minimal impact on the environment. One such alternate bio-energy source is from organic oil yield from tree-borne oilseed (TBO) plants. Harisundan et. al. (2011) reported that biodiesel derived from oil-borne seeds have a potential to supplement fossil fuels which will minimize carbon emission.

Bio-energy is an excellent source of sustainable energy as it can be manufactured from a wide range of agroforestry (agricultural and forestry) raw/waste materials apart from TBO crops. A huge amount of agroforestry biomasses/residues are generated annually in Papua New Guinea (PNG). These biomasses are readily available and are ideal raw materials for conversion into bio-energy sources. SPORE (2011) reported raw materials for biofuel based on lignocellulosic feedstocks e.g. wood, tall grasses, agroforestry residues and algae. Many industries around the world are tapping into biofuel technology.

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For instances, Fiji will operate 23 biofuel mills by 2013 using copra as a feedstock and a South African biofuel company (Stellenbosch Biomass Technologies) will commercialise cellulosic ethanol production (SPORE, 2011). A major sugar producer in PNG (Ramu Sugar LTD) is producing ethanol from sugar cane wastes on a pilot scale. Moreover, wood is an oldest known bio-energy source due to lignocellulosic nature. Walker (1993) and Bowyer et. al. (2007) said that wood can yield various bio-products via chemical conversion (combustion, pyrolysis, gasification and fermentation). An ACIAR (Australian government) supported project is embarking on growing *Eucalyptus pellita* in Markham Valley (PNG) purposely to generate bio-energy for electricity (Mulung, 2013).

The important three TBO crops of interest which yield crude oils for conversion into biofuels as alternate energy source are *Jatropha curcas* L., *Ricinus communis* L. and *Anacardium occidentale* L. These crops yield oils from their fruits (seeds/kernels) called linseed oil, castor bean oil and cashew nutshell liquid respectively and are presently cultivated on commercial scale in African, South East Asia and South American continents. These continents are major suppliers of above crude oils as feedstocks for biofuel industries. Additionally, Harisundan et. al. (2011) mentioned *Pongamia pinnata, Madhuca* spp. and *Calophyllum inophyllum* as important biodiesel (biofuel) tree-crops in India producing substantial amount of crude oils. Biofuel derived from TBO plants has been tried successfully to run engines elsewhere e.g. linseed oil was used in rural Africa to power motors for husking rice grain (SPORE, 2011). Next, Nhantumbo (2011) suggested that crude vegetable oil could be used to operate small machines to generate electricity in remote areas. On a commercial scale, TBO derived biofuel has been tried successfully to power engines of train and aeroplanes. In PNG, the three candidate TBO crops *J. curcas*, *R. communis* and *A. occidentale* are introduced plants during colonial days by European settlers. Since then these crops became acclimatize and thrive on well-drained soils. However, their potential as a source of bio-energy and commercialisation aspects were unknown until recently. Global carbon emission and climate change phenomenon has aroused interest in cultivating TBO crops for oil production for biofuel purpose in PNG. In addition, there is an interest in growing a root crop *Manihot esculenta* (cassava) to source biofuel.

It is well known that crude oil productions have been sourced from other TBO plants for many years in many parts of the world. Fig. 1 provides a list of tradable oil producing crops. These crops are commercially cultivated and form a major backbone in agricultural industries to boost economy in growing nations. The crude oil derivatives provide raw materials as feedstocks for industrial processing into various end products and applications. In PNG, *Cocos nucifera* (coconut) and *Elaeis guineensis* (oil palm) are main agricultural cash crops grown for their oils. Also, there are other commercial cash crops like coffee and cocoa are grown for their seeds' aromatic flavours for confectionery/gourmet industries.

PNG tropical forest hosts diverse seed bearing plant species that are locally known to yield oils (and essentials oils). The seeds/nuts have been providing various traditional benefits/services for the indigenous communities including food (as nutritional sources e.g. calories, oil and protein), medicine, gourmet/confectionery, etc. FAO (2011) highlighted that numerous nutritious seeds and nuts are obtained from the forests in developing countries. In rural forest communities, some TBO plants that become important in dietary are often domesticated from wildings and cultivated. For example, in PNG nutritious oil bearing trees *Terminalia kaernbachii* (galip/okari nut), *Inocarpus fagifer* (ila) and *Pandanus conoideus* (marita) are planted in gardens or near homes. Next, there are certain groups of tropical plants that yield oils collectively known as "essential oils" from different plant tissues. Fig. 3 highlights a list of native essential oil bearing plants. This paper attempts to differentiate oils obtained from plant tissues and thus, the term 'crude oil' refers non-volatile oil borne found in seeds/kernels whilst 'essential oil' refers to volatile oil that is extractable in seeds and other plant parts. Essential oils are tradable commodities with established markets around the world. Many research works are being pursued into indigenous TBO plants in developing countries for their potential to yield crude oils/essential oils for commercialization depending on their ready availability, easy propagation, chemical constituents and their significance for industrial purposes.

This article highlights 3 candidate TBO crops *J. curcas, A. occindentale* and *R. communis* for their crude oils as industrial feedstocks and an important source of bio-energy. Also, the potential significances of the candidate crops for domestication in agroforestry practices in PNG are discussed. Further, indigenous crude oil and essential oil yielding plants are discussed.

Figure 1: Some Commercial Oil Bearing Plants and their Derivatives

Name of Plants	Crude Oil Derivatives
Cocos nucifera (coconut)	coconut oil
Elaeis guineensis (oil palm)	palm oil
Anacardium occidentale (cashew tree)	cashew nut shell liquid (CNSL)
*Canarium indicum**	okari
Terminalia kaernbachii (galip nut)*	okari
Dracontomelon dao (walnut)*	galip
Aleurites moluccana (candle nut)*	candle nut oil
Macadamia integrifolia (macadamia nut)	macadamia nut
Ricinus communis	castor bean oil
Jatropha curcas	linseed oil
Helianthus anuus (sunflower)	sunflower oil
Cucurbita pepo (pumpkin)	pumpkin seed oil
Brassica napus	rapeseed oil
Glycine max	soybean oil
Oleum amygdalae	almond oil
Azadirachta indica	neem oil
Melia azedarach	neem oil

*indigenous tree species

2. Three Candidate TBO Plants for Bio-Energy Sources

2.1 Description of Jatropha curcas *and Properties/End Use of Linseed Oil*

J. curcas belongs to Euphorbiaceae family and is a native shrub to tropical South America and widely distributed in tropical countries. The fruit consists of 4 hard-shell nuts from which linseed oil stored in the inner flesh (cotyledons) are extracted. A green fruit turns yellow when ripe. According to http://en.wikipedia.org/wiki/Jatropha (2012) the Jatropha genus consist *ca.* 175 succulent plants, shrubs and trees. A deciduous shrub *J. curcas* grows up to 6 m tall and thrives on well-drained soil with good aeration and can adapt to marginal soils with low nutrients with less water requirement (van der Vossen & Umali, 2001). The name Jatropha is derived from Greek meaning "physician nutrition" hence the common name **physic nut**. The crude oil extract of *Jatropha* spp contains compounds of medicinal value and highly toxic/poisonous (van der Vossen & Umali, 2001). The toxic property relates to compounds lectin, saponin, carcinogenic phorbol, trypsin and toxalbumin curcin (http://en.wikipedia.org/wiki/Jatropha, 2012). In addition, Igbinosa et. al. (2009) reported a potential antimicrobial activity of *J. curcas* extracts from stem bark. Further, the sap can irritate skin and an ingestion of few untreated seeds is fatal to humans. Based on dry weight, the crude oil content of *J. curcas* is 30% of total weight (Suvi, 2010) and seed yields from plantation range 1,500-2,000 kg/ha with corresponding extractable oil yield of 500-700 litres/ha (Dar, 2007). The crude oil yield and amount of chemical constituents may vary significantly from one locality to another due to soil type and microclimatic conditions.

Out of 175 known Jatropha plants, few species are selectively cultivated on plantation scale for linseed oil for bio-energy source in South East Asia, South and North America and African continents. Many countries (e.g. China, Philippines, India, Brazil, Paraguay, Mali, Mozambique, Tanzania) promote the cultivation of *J. curcas* on plantation scale for biofuel as an environmentally friendly energy source. Industrial countries with high engineering technology (e.g. UK, America and China) are able to convert the crude oil or *J. curcas* into biodiesel and other related products for utilization as substitutes for fossil fuels. The biofuels are specifically for powering automotive engines for machines, land transports and aeroplanes. For instance, biofuel derived from *J. curcas* have been tried successfully to power trains (India); and provided jet fuel for Air New Zealand, Continental Airlines (America) and Air China between 2009 and 2011 (http://en.wikipedia.org/wiki/Jatropha, 2012).

2.2 Description of **Ricinus communis** *and Properties/End Use of Castor Bean Oil*

R. communis is a member of Euphorbiaceae family and widely grown plant for its oil content. Roger & Rix (1999) reported its origin from south-eastern Mediterranean Basin, Eastern Africa and India and spread throughout the tropical regions. It is a fast-growing perennial shrub which can attain 12 m height. It has big palmate leaves with spiny fruit (greenish to reddish purple) capsule containing large, oval, and bean-like seeds (http://en.wikipedia.org/wiki/Castor_oil_plant, 2012). The castor oil is extracted from the seeds/kernels. Ricinus comprised of 4 species grown in the tropics and thrive on well drained soil with good aeration. The name Ricinus is a Latin word for 'tick' as seeds resemble to certain ticks and the common name "castor oil" comes from its use as castoreum perfume. It is also commonly called "palm of Christ" meaning castor oil's ability to heal wounds and ailments. The castor oil has medicinal properties and seeds could produce 40-60% crude oil rich in triglycerides mainly ricinolein. A toxin (ricin) in seeds is related to ricinolein content (http://en.wikipedia.org/wiki/Castor_oil_plant, 2012). A chemical analysis of Philippines grown castor oil indicated the following chemical constituents: 88% ricinoleic acid (12-hydroxy-9-10-octadecenoic acid), 9% oleic and linoleic acids, and 3% palmitic and stearic acids (Pamplona et. al., 1997). Other properties include iodine value 81 to 91, saponification number 176 to 187, melting point -20 to -10ºC and titer 1 to 3 (DBP Report, 1983). Additionally, extracts from other plant's parts (leaves, root and bark) showed antimicrobial, acaricidal and insecticidal activities. Further, castor oil is used in pharmaceutical industry (e.g. cosmetics). Furthermore, castor oil in the processed form called polyglycerol polyricninoleate (PGPR) is used for manufacturing chocolate bar as a cheap substitute for cocoa butter (http://en.wikipedia.org/wiki/Castor_oil_plant, 2012).

R. communis is the most commercially cultivated perennial crop in Eastern Africa, Asia and South America for castor oil to meet the growing demand. An FAO report in 1994 indicated 177,000 tonnes of castor oil seed been traded between 1992-1994 (Pamplona et. al., 1997). According to http://en.wikipedia.org/wiki/Castor_oil_plant (2012) an annual castor seed production is now 1 million tonnes globally. This is >80% increase in annual production. As at June 2008, the major castor oil seed producers were India, China, Brazil and Ethiopia with production of 830,000; 210,000; 91,500 and 15,000 tonnes respectively. The main end use of the crude castor oil is for conversion into biofuel production. Castor oil derivative is known for providing a good lubricant for internal combustion engines including aeroplanes and cars. It has an advantage over petroleum oils at high and low temperatures where castor oil does not mix with petroleum products (http://en.wikipedia.org/wiki/Castor_oil_plant, 2012).

2.3 Description of **Anacardium occidentale** *and Properties/End Use of Cashew Nutshell Liquid*

A. occidentale comes from Anacardiaceae family and is widely grown in the tropical climates. Its scientific name comes from Portuguese meaning upward heart referring to its fruit shape. It is native to northern part of South America and is often referred to as cashew tree. Portuguese spread the cashew plant from South America to India, South East Asia and Africa in the 1560s. Cashew tree is small and attains 10-12 m tall with a short irregularly shaped bole. The fruit called cashew apple is 5-11 cm long and turns yellow or red when ripe (http://en.wikipedia.org/wiki/Cashew, 2012). Cashew trees thrive on sandy soils with low rainfall and are highly prone to pest and disease (SPORE, 2011). The main end use of cashew nut is for industrial medicine, culinary, alcohol and nutrition. A chemical analysis on a byproduct of processing cashew called cashew nutshell liquid (CNSL) is composed of anacardic acids (70%), cardol (18%) and cardanol (5%).

The CNLS has antibacterial, antivenom and antifungal properties. Also, an anacardic acid derivative is used in chemical industry for resins, coatings and frictional materials. Based on chemical analysis of CNLS of African and Brazilian grown materials, Akinhanmi et. al. (2008) described cashew nut oil as drying oil and recommended its use for industrial paints, varnishes, surface coatings and liquid resins. In the Philippines, CSNL was formulated to prepare phenolic varnishes (Palanginan et. al., 2002). In addition, cashew nuts are popular snacks (when roasted and salted) and commonly used in Indian, Thai and Chinese cuisines. Next, the nutritive value of cashew nut is fats and oils as monosaturated fat 54% (18:1), polyunsaturated fat 18% (18:2) and saturated fat 16% (palmitic acid 9% (16:0) and stearic acid 7% (18:0)). Further, cashew apple (accessory fruit) is fermented for manufacturing alcohol/strong liquor in India, Africa and West indies (http://en.wikipedia.org/wiki/Cashew, 2012). Furthermore, Venmalar & Nagaveni (2011) reported that copper incorporated with CNSL and neem oil was used effectively as a wood preservative to protect biodegradation from decay fungi and termite in India.

2.4 Linseed/Castor/Cashew Nutshell Oils: Potential Biofuel Sources

The oil derivatives (linseed/castor bean/cashew nutshell oils) from TBO plants *J. curcas, R. communis* and *A. occidentale* respectively are widely grown as commercial crops for industrial purpose. The crude oils provide important feedstocks for industrial extraction for confectionery, medicinal and pharmaceutical purposes. The chemical properties of their oil contents indicated that they hold huge potential as biofuel energy source. Due to carbon emission from burning fossil fuels (hydrocarbon petroleum products) that causes environmental degradation, the use of biofuel originating from above TBO plants in developed countries has been pursued and its use was proven successful. Also, rise in cost of petroleum products has aroused interest in using cheap alternative fuel source to power engines. In addition, SPORE (2006) reported that given limited fossil fuels left on the planet and reserves estimated between 140-160 Gt (giga tonnes), oil reserves will be exhausted in <65 years if current production and consumption continue as predicted by United Nations Conference on Trade and Development (UNCTAD). Once land scarcity and environmental degradation due to monoculture cultivation of biofuel crops is addressed in certain parts of the world (e.g. Africa) the three candidate species of interest is likely to provide biofuel from renewable energy source. This will eventually address low carbon emission in support of Reducing Emissions from Deforestation and forest Degradation plus Conservation (REDD+) concept and in adherence to global conventions such as Kyoto protocol.

3. Traditional Oil Extraction from TBO Plants and Utilization for Bio-energy Source

In PNG, very little is known about oil extraction from 3 candidate TBO plants (*J. curcas, A. occidentale* and *R. communis*) and their utilization for sourcing energy. There is nil information available on the techniques/methods of extracting oil from TBO plants. Until recently a simply extraction technology used elsewhere in Africa has been tried in PNG. For instance, simple hand held oil press equipment (hydrate processor and oil press machine) is operated by rotating the handle to squeeze out the oily liquid into a container.

Similarly, the utilization of seeds/oily liquid derivatives from the candidate 3 TBO plants is underutilized at present. Although *R. communis* was introduced much earlier than other 2 TBO plants, its castor bean oil extraction and utilization is limited to a very small scale local use only. In rural communities of the highlands region (PNG), mature castor bean seeds are gathered, husked (seeds separated from flesh/seed coat), dried and lit with fire to give light during the nights. Recently seeds of *J. curcas* (linseed oil) are given same treatments to provide light. Sometimes dry seeds are compressed together, solidified and lit for combustion to produce light. Thus, the local name 'Diwai Lam' (meaning lamp tree) is given to *J. curcas* and *R. communis* by rural communities (PNG). In addition, smoke emitted from combustion is used as an insect repellent to mosquitoes. Further, more recently dried seeds are pressed using simple hand-held oil press machine which squeezed out the oily liquid and collected. The crude oil is then strained and used as alternative oil to kerosene for lighting lamps or incorporated as additive in soap making (Suvi, 2010). The resultant solid waste of *J. curcas* after oil extraction can be burnt at homes to produce mosquito repellent smokes.

On a domestic scale, a very little information is known about utilization of oil extracts from native TBO plants for bio-energy sources in PNG. Except that coconut oil is extracted and manufactured for lotions for hair and body as well as biofuel for operating engines in Kar Kar Island (Madang Province). However, there are evidences of traditional utilization of oil derived from TBO plants for food, medicinal and ceremonial purposes. For instance, coconut oil is long being used for preparing varieties of confectionery dishes for food. Also, oil extracts from fruits of *Aleurites moluccana* and *Pandanus conoideus* are used for flavouring food in the highlands of PNG. Likewise, a dried bark of *Cinnamomum* spp. is chewed as herbal medicine. Additionally, an essential oil (digaso oil) extracted from the bark of *Campnospermum* spp. is used in body painting in traditional ceremonial dance (Gebia, 2012). Similarly, a reddish coloured substance obtained from the mature fruit of *Bixa orellana* is used for body painting for same reason. Further, Gusamo et. al. (2008) reported that a pounded paste made from the fruit of *Atuna racemosa* is used for pasting holes and crevices in canoes by coastal people to prevent water penetrations. Furthermore, neem oil (*Azadirachta indica*) extract from the seed kernels have medicinal and insecticidal properties and used to treat skin diseases and control insect pests (Schneider, 1999).

With rise in prices for petroleum products (e.g. kerosene and diesel), PNG rural communities need an affordable alternate fuel to provide lights and power motor engines.

This paper anticipates that once a simple and effective extraction technique is known for extracting oil from the TBO crops, there will be an increase in their utilization in rural communities as substitutes for kerosene and diesel.

4. Potential of Candidate TBO Crops for Domestication in Agroforestry Practices

The three candidate TBO crops (*J. curcas, R. communis* and *A. occidentale*) naturalized well in PNG environmental conditions since their introduction. To date, there is no proper documentation on their growth performances and yield of the three TBOs in PNG. Thus, their promotion for cultivation as alternative commercial crops has not been realized.

J. curcas and *R. communis* are perennial trees and grow prolifically from 0-2000 m above sea level (a.s.l) with short rotation age. Presently, they are planted as ornamentals near homes or roadsides in PNG. *J. curcas* can be propagated from seeds and cuttings vegetatively whilst the *R. communis* is grown from seeds only. From observations at 800 m a.s.l. in Bulolo, Morobe Porvince, *J. curcas* fruit within 2-3 months of planting along roadside. Likewise, *R. communis* is said to fruit within 4-5 months. A similar observation was made for the above crops planted in Goroka, Eastern Highlands Province (1500 m a.s.l). Harakuwe (2011) added that seeds of *R. communis* buried underground were seen germinating after pigs have dug over. Comparatively, *J. curcas* is deciduous and shed leaves while *R. communis* is non-deciduous. On the other hand, *A. occidentale* is a small tree and grows best in the lowlands from 0-800 m a.s.l. It may take long to fruit (7-12 months) unless grown on fertile soil with suitable climatic conditions fruiting can be expected much earlier.

Given prolific growth performances and fruiting characteristics, it is optimistic that the above TBO crops could be cultivated on plantation scale in PNG. They hold huge potential as alternative cash crops for growing in monoculture or mix-planting (intercropping) in agroforestry systems. For instance, a Jatropha farmer from Minj, Jiwaka Province was introduced by a Chinese tourist in 2008 and planted 2000 trees and within 4 months the fruits were ready for harvest (Post Courier, 2012). Also, in East Sepik Province, a large project is embarking to plant 110,000 ha with *J. curcas* among other cash crops in agroforestry (Nicholas, 2011). Next, a Jatropha biofuel advocator (Thompson Benguma) suggested a monetary return of K10,000.00 per ha after 2 years planting (The National, 2011). Further, Pangkatana (2012) in a Post Courier Newspaper reported that a cashew nut (*A. occidentale*) trial model plot has been established successfully in the southern region (Central Province) where environmental conditions are favourable for growth of the crop. A total of 40,000 trees will be planted over 5 years that is anticipated to earn K2.5 million when cashew nuts are harvested. Reports from trial plantings of these crops overwhelmingly suggest that they could be domesticated in agroforestry practices in PNG. In agroforestry, intercropping above three TBO crops with other cash crops is desirable. In this case, short and long term crops are grown together over a same landmass so that diverse products as well as crude oils for biofuel are produced. As the candidate TBO crops are perennial with short rotation age, they can be intercropped with long-term tree crops e.g. cocoa, coffee, rubberwood, teak, kamarere and fruit trees. This will solve land scarcity problem faced in rural communities. For instance, in Africa, this issue arose where large landmass was taken up by TBO crop monoculture and there was no land for growing food crops that resulted in rise in prices of goods (Nhatumbo, 2011). Also, intercropping minimises outbreak of pests and diseases, as is the case with *A. occidentale* (SPORE, 2011).

The significant benefits imminent from commercial cultivation of candidate TBO crops in agroforestry systems are: (1) address two burning social and environmental issues simultaneously: sustainable development and climate change adaptation/mitigation via carbon sequestration (Whalen, 2011), (2) bring economic service to rural communities to increase income and alleviate poverty, (3) in remote communities where fossil fuel is inaccessible, oils could be extracted for biofuels as alternative energy requirements and relieve pressure on forest biomass (Nhamtumbo, 2011) and (4) leguminous TBO plants and *J. curcas* fix nitrogen in their roots for soil enrichment and thus, Rao and Halim (2009) stressed that there is a potential to cover degraded lands of PNG with biofuel crops. Also, Jose (2009) added other services of agroforestry system as biodiversity conservation and air/water quality improvement.

5. TBO Plants of Papua New Guinea

5.1 Native TBO Trees for Crude Oil Production

Many native tropical plants provide diverse sources of crude oils. The oils are limited to traditional end uses only. Except for major agricultural cash crops (coconut, oil palm, coffee, cocoa) that are grown on large-scale plantations, very little is known about indigenous TBO plants for their commercial production and utilization.

Some native TBO plants of interest are provided in Fig. 2. Based on traditional uses of crude oil derivatives from native plants, scientific studies into chemical properties of oil content (as well as domestication/cultivation and processing/utilization) must be pursued and documented for possible commercialisations. Such studies on crude oil derivatives could become important feedstocks for industrial processing for confectionery/gourmet, pharmaceutical and medicinal purposes. For instance, a collaborative work by Australian government (ACIAR) and PNG National Agriculture Research Institute (NARI) has investigated the potential of a local TBO tree *Canarium indicum* (galip nut) for edible oil and documented on its domestication and commercialisation aspect (ACIAR Annual Report, 2007). Other case studies include chemical analysis of *Atuna racemosa* fruit extract for natural adhesive (Gusamo et. al., 2008) and fruit latex of *Ficus botryocarpa* showed antibacterial activity (Wau et. al, 2010). Also, Schneider (1999) reported medicinal and insecticidal properties of neem oil derived from seed kernels of *Azadirachta indica* and *Melia azedarach*. Further, other promising native TBO trees that require further study into their crude oil contents include *Aleurites moluccana, Terminalia kaernbachii, Dracontomelon dao, Pandanus conoideus*, *P. jiulianettii*, *Castanopsis acuminatissima*, *Anisoptera thurifea, Semecarpus* spp. and *Inocarpus fagifer.* In particular, *Semecarpus* spp. (Anarcadiaceae), which resembles to cashew nut in terms of its fruit/nut, has edible oil content (Gebia, 2012). Additionally, another related species *Campnosperma brevipetiolatum* (Anarcadiceae) has oily content in its kernel/nut. The crude oil contents of these species from Anarcadiaceae family needs to be researched for their chemical constituents.

Elsewhere in Asia, native TBO trees are well studied and documented. For example, an oil extract from the seeds of *Aleurites moluccana* finds many end uses in industrial applications e.g. pharmaceutical (paints, varnishes, linoleum, soap manufacture, wood preservation), for illumination (lamp oil, candles) and medicinal (mild purgative, against hair loss) (Siemonsma, 1999). Next, Ong (1998) reported oil extracted from seeds of *Hydnocarpus sp* is widely used in pharmaceutical purposes in Asia. Also, a rubber seed oil of *Hevea brasiliensis* from the Philippines was characterized and found to have linoleic, oleic and linolenic acids for industrial applications (Bato & Fidel, 2002). Further, an Indonesian herbal oil product derived from *Pandanus conoideus* (marita) is being sold in Port Moresby (PNG) to treat various ailments e.g. cancer/tumor, stroke/high blood pressure, diabetes, liver/kidney problems, osteoporosis, eye disorders, cleanse and detoxify body system (The National, 2011). Furthermore, a latest discovery of butter (oil) derivative from kernels of *Mangifera minor* (mango) is rich in Vitamin C and has cosmetic properties to treat dry skin and brittle hair (SPORE, 2012). Mango will be beneficial for tropical countries like PNG where it is widely grown for its delicious fruit and kernels are often discarded. Mango kernels can now find a niche market for utilization in pharmaceutical industry.

Figure 2: Indigenous Tree-borne Oilseed Plants

Name	Family
Aleurites moluccana	Euphorbiceae
Canarium indicum	Burseraceae
Terminalia kaernbachii	Combretaceae
T. impediens	Combretaceae
Dracontomelon dao	Anacardiaceae
Pandanus conoideus†	Pandanaceae
P. brosimos	Pandanaceae
Castanopsis acuminatissima	Fagaceae
Anisoptera thurifea	Dipterocarpaceae
Inocarpus fagifer	Leguminosae (Papilionadae)
Semecarpus spp..	Anacardiaceae
Buchanania spp.	Anacardiaceae
Garcinia spp.	Clusiaceae
Barringtonia asiatica	Lecythidaceae
Pouteria spp.	Sapotaceae
Chrysophyllum roxburghii	Sapotaceae
Palaquium sp	Sapotaceae
Campnosperma brevipetiolatum	Anacardiaceae
Pometia pinnata	Sapindaceae
Chisocheton ceramicus	Meliaceae
Antiaris toxicaria	Moraceae
Hernandia ovigera	Hernandiaceae
Guioa spp.	Sapindaceae
Atuna racemosa	Chrysobalanaceae
Callophyllum inophyllum	Clusiaceae
Pimelodendron amboinicum	Euphorbiaceae
Pongamia pinnata	Fabaceae
Castarnospermum australe	Leguminosae
Mangifera minor	Anacardiceae

†locally known as marita (PNG) and it is cultivated for oily edible flesh/pericarp

5.2 Native TBO Trees for Essential Oil Production

Certain tropical TBO plants are also produce essential oils of commercial value and are widely traded. Bisana et. al. (2002) added that essential oils are derived from secondary plant metabolism and composed of a mixture of chemical compounds found in seeds, fruits, flowers, leaves, barks and roots. Many essential oils are major feedstock sources for confectionery, medicinal, pharmaceutical and cosmetic industries. Fig. 3 has a list of some native trees that yield essential oil. In PNG, probably the first reported essential oil was sandalwood oil found in the heartwood of *Santalum spicatum* and *S. macgregorii* (Loneragan, 1990; Doran et. al., 2005). In 1997, 'eaglewood/agarwood oil' was discovered and commercially exploited from *Aquilaria malaccensis* and *Gyronopsis ledermannii* (Zich & Compton, 2001) where essential oil was extracted from the heartwoods. A more recent discovery is the 'waria waria oil' extracted from the leaves of *Asteromyrtus symphyocarpa.* Waria Waria Oil is now commercially being developed in Western Province covering 476,000 ha managed by PNG Sustainable Development Programme (Elapa, 2011). Further, *Eucalyptus* spp. grown in PNG plantations has potential for oil production. In the Philippines, Dionglay et al. (2003) reported that an essential oil was derived from *E. camaldulensis* leaves. Also, an Australian grown *Castanospermum australe* is said to posses medicinal property to combat AIDS (Whitmore, 1990) and an inflammable oil tapped from Amazonian legume tree *Copaifera langsdorfii* is used as alternate kerosene (Whitmore, 1998). A comprehensive documentation on essential oils can be found in PROSEA Handbook No. 19 edited by Oyen & Dung (1999).

Figure 3: Indigenous Essential Oil Bearing Trees

Plant Species	Plant Part that Yield Essential Oil	Type of Oil Derivative
Santalum spp.	heartwood	sandalwood oil
Aquilaria malaccensis	heartwood/root	agarwood/eaglewood oil
Gyropsis ledermannii	heartwood/root	agarwood/eaglewood oil
Asteromyrtus symphyocarpa	leaves	waria waria oil
Eucalyptus spp.	leaves	eucalypt oil
Cryptocarya massoia	bark/heartwood/fruit	massoia oil
Campnospermum spp.	bark/sap	digaso oil
Myristica spp.	fruit/seed	nutmeg oil
Anisoptera thurifera	bark/sap	mersawa oil*
Vatica papuana	bark/sap	vatica oil*
Canarium macadamii	bark/sap	okari oil*
Garciania spp.	bark/sap	garcinia oil*

*known locally in PNG only

6. Conclusion and Recommendations

The three TBO crops (*J. curcas, R. Communis* and *A. occidentale*) acclimate well in PNG environmental condition and are ideal candidate species for domestication for plantation purpose. Cultivation of *A. occidentale* is restricted to lowlands up to montane forest (800 m a.s.l.) whilst the *J. curcas* and *R. communis* can be cultivated from lowlands up to high altitudes. Promising growth performances from ornamental and trial plantings demonstrate that they could be adopted as planting stocks for intercropping in agroforestry practices. Also, native TBO trees with potential of yielding substantial crude oil could be domesticated for agroforestry system.

A successful adoption, cultivation and promotion of TBO plants on large-scale agroforestry practices/agri-businesses in developing countries like PNG will bring number of services for the rural community. The crops become alternative cash crops for income generation and provide bio-energy requirements. In particular, trees with multipurpose end uses e.g. leguminous trees (*Inocarpus fagifer* and *Pongamia pinnata*) or fruit trees (*Mangifera minor* and *Terminalia* spp.) will provide crude oil, wood, fuelwood, fodder, fruit, medicine and for soil improvements. In addition, such crops will play vital role in carbon mitigation by harnessing atmospheric carbon dioxide.

To support the commercial cultivation of these TBO crops, Rao & Halim (2009) recommended systematic pilot trials to be established in different parts of the country to assess the suitability and economic viability of various biofuel crops. Additionally, a qualitative research into chemical constituents of crude oil contents based on PNG grown materials is highly recommended. The government, through its tree crop policy, could create investment opportunities for commercial development of the crops. SPORE (2011) supported that active government policies will drive the interest and promote smallholder participation in agroforestry for biofuel crop cultivation. Next, bio-energy value chain has to be installed with private sector playing a major role in harvesting and processing of the bio-energy products. Thus, the onus is with the national government via the offices of Department of Agriculture and Livestock (DAL) and PNG Forest Authority (PNGFA) to promote these crops.

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