Castor (*Ricinus communis*)

Potential of castor for bio-fuel production

Prepared by FACT Foundation

Castor plant

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1 PREFACE

1.1 Foreword

This FACT sheet is based on various inputs, from published papers, internet resources, but also from own experiences with Castor in the FACT-Gota Verde Project in Honduras. Main target groups of this document are parties involved in the development of sustainable biofuels in developing countries (NGO's, small and medium sized enterprises, local entrepreneurs, local governments, local farmers and farmers groups). Our main aim is to generate, collect and analyze information and make this knowledge available for the development of projects, that:

- bring development to the local population with a bio-fuel component;
- increase food security or at least do not threaten food security;
- have positive or at least no negative impacts on the environment and biodiversity;
- reduce greenhouse gas emissions; and
- have a positive energy balance.

This document will be presented as a living document on the FACT website and will be updated when new information on castor becomes available.

We hope the document is useful in making well balanced decisions in new research and projects involving castor.

For more information or comments please contact us or visit our website:

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1.2 Acknowledgements

This publication is made available in English by the FACT Foundation. Quite some inputs were taken from the Dutch study "Nieuwe grondstoffen voor biobrandstoffen – alternatieve 1e generatie energiegewassen", prepared by Wageningen University, commissioned by Senternovem (the current AgentschapNL). It was first published in Dutch in August 2009. FACT Foundation thanks Mr. Wolter Elbersen (WUR-ASFG) and Mr. Leo Oyen (WUR-PROTA), as well as Mr. John Neeft (AgentschapNL) for their approval and cooperation on this publication.

FACT Foundation also thanks Peter Moers, coordinator of the Gota Verde project and Titus Galema, technical advisor of the same project for their valuable contribution.

2 SUMMARY

Name: castor oil plant (En). Ricin (Fr), Castor, castorplant, wonderolie, wonderolieboom (NL).

Latin name: *Ricinus communis* L.

Family: Euphorbiaceae

Castor is a fast growing ever-green shrub that produces seeds with a high oil content (35-55%). Cold pressing yields 30-36% oil measured by weight. Warm pressing (>70°C) yields 38-48%.

Castor oil has been used for at least 6000 years. The highly viscous oil is currently used for more than 700 products including medicine, cosmetics, lubrication, paints, and nylon. It is a hardy plant that will produce under conditions where other crops fail. It thrives well under the same conditions as Jatropha.

In the wild it is a perennial that bears seeds for up to 15 years and grows to the size of a small tree. Under cultivation it is usually grown as an annual crop. It has huge (15-45 cm) palmate (fingered) green to reddish leaves.

Castor oil has long been used as lubricant in engines but only recently has research on the use of Castor oil as a biofuel started. The high viscosity presents challenges when used as PPO (pure plant oil). It can be processed into a good biodiesel, that needs to be blended with diesel for the same reason. The seeds contain extremely poisonous substances that remain in the press cake which can therefore not be used for animal feed. The oil is non-toxic.

Parameter	**Unit**	**Minimum**	**Average**	**Maximum**	**Source**
Seed yield	Dry tonne/Ha/ year	**0.3**	**0.5**	**5**	
Rainfall requirements	Mm/year	**750**		**1000**	**[1]**
Oil contents of seeds	% of mass	**35**	**45**	**55**	
Oil yield after pressing	% of mass of seed input	**30**	**40**	**48**	
Energy content of oil	MJ/kg		**36**		**[2]**

3 POTENTIAL OF CASTOR FOR BIO-FUEL PRODUCTION

3.1 Status as an Energy Crop

Castor is currently considered experimental as a biofuel feedstock and mainly a crop of interest for small scale farmers in areas with challenging agro-climatic conditions. Under mechanised high-input farming other energy crops are likely to be more profitable.

Castor oil fetches a higher price on the world market than other vegetable oils and is therefore not attractive as a raw material for biofuel production. Tax incentives such as the ones provided in Brazil can change this situation. In dry and isolated areas where biofuel is produced and consumed locally it is sometimes one of the only options for oil crops and it may be competitive due to the low transport costs involved compared to importing oil.

The Brazilian government supports Castor as a biofuel crop for small farmers in the North-East of the country. In India and elsewhere it is being inter-cropped with other types of crops sometimes with Jatropha as a biofuel crop.

Mixing Jatropha and Castor can reduce production risks and during an upstart phase Castor can give full yields in the first year(s) whereas Jatropha yields will reach their maximum yield after five to eight years.

The low value of the seed cake due to its toxicity reduces the overall profitability of Castor compared to non-toxic oil crops where the press cake can be sold as a high-protein fodder supplement. It can be returned to the field as organic manure and since the oil contains very few plant nutrients this practice prevents exhausting the soil.

3.2 Centre of Origin and Current Distribution

Castor probably originated in North-East Africa from where it spread thousands of years ago to the Mediterranean, the Middle East and India.

Today Castor is cultivated and growing in the wild throughout the drier tropical, warm-temperate and subtropical regions between 40° South to 52° North. It is found at altitudes from sea level to about 3,000 m in areas where there is no or only slight frost.

3.3 Climate and Soil Requirements

Castor is a C3 pathway plant that grows optimally at constantly high temperatures of 20-26° C but can tolerate temperatures between 0° and 40° C. In colder areas it only grows well if the summers are sufficiently warm (e.g. Southern Spain). If the temperature is too low or too high Castor will fail to set seeds.

It is a pioneer plant that is often growing in flood zones, abandoned farmland and along roads. Without disturbance it will soon be succeeded by grass and trees.

About 500 mm of rain is required between planting and harvesting but it can grow in areas with lower as well as much higher rainfall. Depending on the variety it requires a 140-180 day growing season. Under severe water stress no seeds are set.

Too high air humidity increases pest and mould problems. 30-60% humidity is considered ideal.

The optimal altitude is 300-1800 m.a.s.l.

Soil requirements are modest and Castor can grow in stony land unsuitable for other crops with pH ranging from 4.5 to 8.3. Water logging is tolerated only for short periods so the soils must be well drained. Sandy and clayey loam is preferred.

Nitrogen is the most important nutrient determining seed yield. However, excessive amounts of nitrogen lead to heavy vegetative growth without increased seed yield.

Castor shows little response to phosphorus.

Hard pans, e.g. sub-surface laterite pans, can hinder normal development of the up to 3 m long tap root and should be broken up if possible. The tap root grows particularly deep in low rainfall areas. The lateral roots extend about 1 m from the stem.

Although Castor can be grown in poor soils under difficult climatic conditions it will yield much better under higher rainfall and on fertile soils. In many areas irrigation will boost the yield and if the temperatures are sufficiently high throughout the year two crops can be harvested every year.

3.4 Description of the Crop

Castor plants show a lot variation in morphology and agronomic characteristics but no comprehensive classification has been undertaken. It is both self- and cross-pollinated by wind. All varieties can be cross pollinated. An isolation distance of 300-700m will prevent wind pollination between separate stands.

The plant has several branches each terminated by a spike that is up to 30 cm long. When mature, each spike carries 15 to 80 greenish to purple capsules, with a prickly or smooth surface. Each capsule contains three seeds that can be oblong or round and range in colour from black to white mottled. Their resemblance to blood filled ticks has inspired its Latin name: *ricinus* is Latin for tick. The name "castor oil" probably comes from its use as a replacement for *castoreum*, a perfume base made from the dried perineal glands of the beaver (*castor* in Latin).

In wild Castor the seeds do not ripen simultaneously and seeds are shed when the fruits open spontaneously at reaching maturity leading to considerable seed losses. Repeated harvesting of the same crop is therefore required. In wild Castor seeds are smaller with smaller kernels and more shell and thus contain less oil. Improved varieties show fewer tendencies to seed shedding and all seeds mature within a shorter time span. Most improved varieties have larger seeds, are shorter and therefore easier to harvest.

Examples of varieties are Baker 22, Baker 44, Conner, CS-9, II23, GCH-series hybrids, Hale, Hazera, HD912, IAC 2008, Kansas, Lynn, McNair 1, Negus, Pronto, Rica, SKI-7, S-56, T-3, UC-53, and Venda. Some of the older varieties like Hale and Lynn are now used mainly for production of hybrid seeds.

3.5 Toxicity

Castor is one of the most poisonous plants in the world due to ricin contained in the bean, stem and leaves. Ricin is not found in the expressed oil but remains in the press cake. Just 4 to 8 beans can kill an adult person, a horse or an ox. However, cases of poisoning are rare. Animals sense the toxicity and avoid it.

During processing care should be taken to keep dust levels low and/or wear protective gear to avoid inhaling ricin laden dust. Care should be taken to avoid situations where Castor seeds could accidentally enter the food chain, e.g. through inter-cropping with food crops, shared storage or processing facilities.

The toxins also protect Castor against some insects.

3.6 Growth, Propagation and Planting

Castor is always propagated from seeds that are typically directly planted at a depth of 5-8 cm at a density of 10,000-40,000 plants per hectare, depending on water availability. If Castor is intercropped the density may be as low as 4,000 plants per hectare. Seeds are viable for about 3 years.

Castor can also be planted as a perennial crop. In that case the plants are cut back rigorously after the canopy is closed and they grow too big. New fruits will then appear on the new wood.

It is important to select the right variety. This has to be done based on the climate, soil and seasons in the area to be planted. Planting needs to be timed such that seeds can dry on the trees for at least 2 months (Galema, 2011 - pers. comm.). In the Honduras Gota Verde project in Yoro, that FACT was involved in, the best variety was a Brazilian called 'Nordestina'.

Planting should only be done when the soil is thoroughly moist. Germination is slow, taking 1-3 weeks. 2-4 seeds are used per hole and thinned to one plant per hole after emergence.

Like with any other crop, Castor should be rotated. In India it is rotated with finger millet, groundnuts, cotton, dryland chillies, tobacco or horse gram.

Young Castor plants do not compete well with weeds. Usually weeding is required two times which makes it more labour intensive than some other crops. It also makes the soil more vulnerable to surface erosion.

3.7 Harvesting

Harvest takes place in the dry season. If shattering varieties are used repeated harvesting is required. When harvested by hand the spikes are usually cut or broken off before completely dry and must immediately be dried on a concrete slap or cleared soil. Many capsules will crack open when they dry and the seeds can easily be separated from the hull. Capsules that refuse to open are beaten with sticks and the seeds are separated through winnowing.

Stems and leaves are usually left in the field to fertilize the soil as they have little economic value at most localities. In China leaves are sometimes used to feed silk worms. Fibres from the Castor plant can be used for paper and wall board.

In mechanical harvesting, modified combine harvesters are normally used, which partially separate the immature capsules. In this case, the plants must be leafless, which may require the use of defoliants.

3.8 Pest and Diseases

A large number of pests and diseases can attack Castor but usually they do not cause harm of economic importance. More than fifty different fungi are known to attack Castor; Striga parasitizes the plants; nematodes have been found in Castor; and several insects are pests, including the Capsule borer (*Dichocrocis punctiferalis*) that in India bores into young and ripening capsules, and the Castor semilooper (*Achaea janata*). In Tanzania damage by capsid and mirid bugs cause immature fruit to drop. Green stinkbugs, leaf-hoppers, leaf-miners and grasshoppers feed on the leaves.

Rust (*Melampsora ricini*) attack the leaves world-wide.

The deep roots usually prevent the uprooting of Castor by wind storms but because it is tall it can break.

3.9 Yields and Conversion into Biofuel

Yields under small holder conditions without irrigation are typically 300-400 kg/ha. Irrigation can double the yield. In India the average yield is 560 kg/ha, in Brazil 900 kg/ha and worldwide 1100 kg/ha. Under mechanised high-input farming up to 5000 kg/ha/year can be achieved. [27]

3.10 World Market

The share of castor seed is less than 0.15% of total world trade of oil seeds. At present, the annual world yield of castor seeds is about 1.3 million tonnes, which corresponds to about 0.55 million tonnes of castor oil. Since the beginning of the 1970's, castor oil seed production increased continuously but, in some cases, subjected to yearly fluctuations of 20%, especially due to storm damage in the main producing regions.

About half of all the castor oil produced in the world is exported, with India dominating the market with a share of 80%. Presently, India produces over 90% of the castor oil in the entire world. [1]

The production figures for 2008 (FAO Stat):

Country	**tons**
India	1,123,000
China	220,000
Brazil	120,499
Mozambique	52,071
Thailand	11,330
Paraguay	10,500
Ethiopia	7,000
Viet Nam	5,000
South Africa	4,900
Pakistan	4,023
Angola	3,500

The prices of castor oil vary considerably due to fluctuations in production and also due to speculation. The average price in the last decade was about 900 US$/metric tonne, which is almost twice the price of rapeseed oil in Germany (Figure 2).

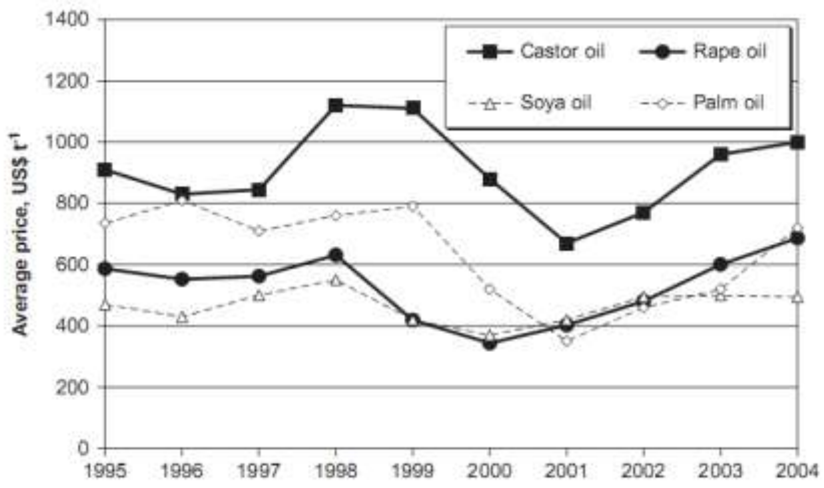


Illustration 2: Price trend of castor oil and other vegetable oils in Germany (not adjusted for inflation) (Volkhard & da Silva, 2008).

Oil content of seeds varies from 35 to 55%. Cold pressing yields 30-36% oil measured as weight. Warm pressing (> 70°C) yields 38-48%.

4 CONVERSION & REFINING

4.1 Conversion & refining in an industrial way

The description below is based on an industrial process as described in the sources: Ref: http://www.whc-oils.com/industrial-castor-oil.html ,

Summary of the process

Castor seeds are generally cleaned and sorted by machines and the oil is extracted by pressing the seeds, one to three times.

During cold pressing, which is preferred for pharmaceutical and cosmetic use, the oil yield is 30 to 36% of the seed mass. Warm pressing (> 70 °C) yields about 38 to 48%. The remaining oil, to a large extent, can be extracted by solvents. Good processing leaves behind only 1 to 2% of the oil in the pressed cake (Rehm, S. et al., 1984). The bean shaped seeds usually contain 40 to 55% oil. With a mean oil content of 47% and mean estimated extraction efficiency of 90%, the world average oil yield (based on 1,1 ton seed/ha) is around 460 kg/ha, although a maximum yield of 2000 kg/ha may be possible. Thus castor is among plants with a high oil yield potential.

Preparation for pressing

The seeds are collected when ripe: as the capsules dry, they open and discharge the seeds. In Honduras manual dehulling was difficult as the fruit hull is sturdy (more than with Jatropha). The had some good results with a peanut dehuller. Also, fruit jackets can be included in pressing but this produces a greenish coloured oil (Galema, 2011 – pers.comm.).

The seeds are then cleaned, decorticated, cooked and dried prior to extraction. Cooking is done in order to coagulate protein, which is necessary to permit efficient extraction, and to free the oil for efficient pressing. It is done at 80°C, under airtight conditions. After cooking, the material is dried at 100°C, to reach a moisture content of approximately 4 percent.

Extraction by pressing & solvent extraction

First stage of extraction is pre - pressing using a high pressure continuous screw press – expeller. The usual capacity of the presses used in the 1950s in the USA and Mexico was over 24 tonnes of seed/day [Dunning, 22]. The expeller usually consists of a barrel containing a stainless steel helical screw. The pitch of the screw flights gradually decreases towards the discharge end, to increase the pressure on the pulp as it is carried through the barrel. Extracted oil is filtered, and collected in a settling tank. Material removed from the oil, called foot, is fed back into the stream of fresh material. Material discharged from the press, called cake, contains 8 to 10 percent oil. It is crushed into coarse meal, and subjected to solvent extraction with hexane or heptane. Continuous processing is used, based on the principle of counter current flow of solvent and oil bearing material. The oil is removed effectively, as the material comes into contact with increasingly purer solvent. After extraction, solvent is removed by distillation, and the resulting oil is processed in similar manner as oil from the pressing step.

In Honduras, with small scale equipment (a tinytech20 press – up to 100kg seeds/hour, costs about 20kUSD) the pressing was difficult. Important lessons here were to have an initial moisture content of 8%, heating the seeds to 80°C, and avoiding too high pressure and temperatures in the press which results in polymerization of the oil. Prior to pressing the seeds received a steam treatment to heat and moisturize the seeds (Galema, 2011 – pers. comm.).

Cleaning and refining of the oil

Once the oil has been expressed from the seed, it is necessary to remove any impurities from the oil that makes it such an important commodity. The oil is essentially a pure triglyceride, and contains almost 90% of glyceryl tricinoleate. It is the ricinoleic triglyceride that is needed in order to produce high quality castor oil that will be used for the chemical industry. Characterizing properties of castor oil include a higher density, viscosity, and reactivity than common triglycerides found in other vegetable oils. These properties are exploited when refining the oil from the impurities. The steps to refining the crude oil include settling and degumming of the oil, bleaching, neutralization, and deodorization of the oil.

The settling and degumming of the crude oil is done to remove the aqueous phase from the lipid and to remove phospholipids from the oil.

Bleaching of the oil results in the removal of colouring materials and the removal of remaining phospholipids and oxidation products through the adsorption of the impurities to neutral clay. Care must be taken because a highly acid activated clay can react with the oil and cause an undesirable dehydration reaction.

Neutralization can be done in one of two ways: by alkali (chemical) or steam stripping (physical) means. The neutralization step is necessary to remove free fatty acids from the oil. Caustic soda (alkali) is mixed in the proper amounts and the aqueous solution (called soapstock) is removed, leaving the neutral oil behind. Unfortunately, the use of alkali to neutralize the oil results in poor soapstock separation and high neutral oil losses. This is why steam stripping is preferable. Steam stripping is done under vacuum to remove moisture, free fatty acids, odour bodies, and other impurities from the oil. Because it is performed under vacuum conditions, the oil can be kept at a low temperature, preserving its chemical structure and not subjecting it to temperature in which undesirable dehydration reactions can occur. Ref: [21]

Deodorization is required for certain cosmetic or medicinal products but is not relevant if the oil is used for biofuel only.http://www.whc-oils.com/industrial-castor-oil.html

4.2 Conversion & refining, small scale-rural conditions

For rural areas, like in Sub-Saharan Africa, that are considering to start producing biofuels from oil crops like Castor, a supporting industry does not yet exist. Suppliers of equipment, both presses and chemicals, are non-existent.

Moreover there is no qualified staff or personal trained in these subjects. Current experiments are mostly small scale, with press capacities of less than 1 ton per day.

This means that for the coming years simplified methods will be applied, which are not proven yet, and a lot of applied field research still has to be done to solve problems when they occur.

For castor oil production as PPO for the local market probably the following methods will be applied:

Only mechanical pressing with small strainer presses (up to 1 ton/day), no solvent extraction applied (no chemicals). Cleaning and refining restricted to sedimentation and decanting, plus simple degumming and neutralization methods.

From experiments with conversion of castor in the Gota Verde project in Honduras, the following recommendations were made;

For pressing; preheat the seeds (kernel + shell) up to about 80° C before pressing.
For cleaning: Sedimentation by gravity was found not to work and filtering is necessary. Use air to press the crude oil through a barrel vessel with a removable filter (instead of using bag filters with gravity) [Kokkelman, 24].

For refining: use a simple degumming method, and neutralize with caustic soda

5 PRODUCTS & USE

5.1 General products and use

The uses of castor oil have changed over the years. Sixty years ago, castor oil was used for lamp oil, medicinal purposes and as a general industrial lubricant. Soon afterwards, chemical engineers were able to produce derivatives of the oil that were of even more benefit to man. The chemical structure of castor oil is of great interest because of the wide range of reactions it affords to the oleochemical industry and the unique chemicals that can be derived from it. These derivatives are considerably superior to petrochemical products since they are from renewable sources, bio-degradable and eco-friendly.

Castor oil forms a clean, light-coloured soap, which dries and hardens well and is free from smell. Sulfonated (sulfated) castor oil, or Turkey Red Oil, was the first synthetic detergent after ordinary soap, and other forms of the oil became important for the treatment of leather, industrial lubricants, and other industrial uses. Castor oil is regarded as one of the most valuable laxatives in medicine. Castor oil is an excellent solvent of pure alkaloids and such solutions of atropine, cocaine, etc., as are used in ophthalmic surgery [3].

Today, there are many uses of castor oil and its derivatives such as: polyamide 11 (Nylon 11) engineering plastic, lubricating grease, coatings, inks, sealant, aircraft lubricants, surfactants, emulsifiers, encapsulators, plastic films, plasticizer for coatings, and components for shatterproof safety glass. It is an essential component in some artificial rubbers, in various descriptions of celluloid, and in the making of certain waterproof preparations, and one of the largest uses is in the manufacture of transparent soaps. It also furnishes sebacic acid which is employed in the manufacture of candles, and caprylic acid, which enters into the composition of varnishes. Castor oil has even made its way into cosmetics and related products. Ref: [21].

Partial oxidation of Castor oil at 100° C produce ”blown oil”, an oil that stays fluid at low temperatures and is used a lot for hydraulic brake fluid, and as weakener in ink, varnishes and leather. Nowadays it is an important resource for very high quality lubricants. They are used for engines working under extreme conditions, like jet engines for airplanes. [3]

Castor oil qualities with regard to lubrification: For any fluid to act as a lubricant, it must first be "polar" enough to wet the moving surfaces. Next, it must have a high resistance to surface boiling and vaporization at the temperatures encountered. Ideally the fluid should have "oiliness", which is difficult to measure but generally requires a rather large molecular structure. Castor oil meets these rather simple requirements in an engine, with only one really severe drawback in that it is thermally unstable. This unusual instability is the thing that lets castor oil lubricate at temperatures well beyond those at which most synthetics will work. Castor oil is roughly 87% triglyceride of ricinoleic acid, [$(CH_3(CH_2)_5CH(OH)CH_2CH{=}CH(CH_2)_7COO)_3(OC)_3H_5$], which is unique because there is a double bond in the 9th position and a hydroxyl in the 11th position. As the temperature goes up, it loses one molecule of water and becomes a "drying" oil. (See: Another look at the molecule.)

Castor oil has excellent storage stability at room temperatures, but it polymerizes rapidly as the temperature goes up. As it polymerizes, it forms ever-heavier "oils" that are rich in esters. These esters do not even begin to decompose until the temperature hits about 650 degrees F (345° C). Castor oil forms huge molecular structures at these elevated temperatures - in other words, as the temperature goes up, the castor oil exposed to these temperatures responds by becoming an even better lubricant! Ref: [25,Bert Striegler]

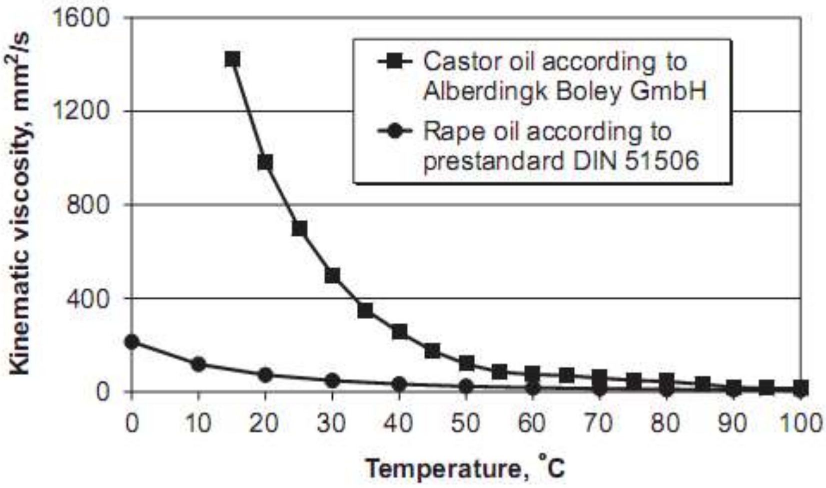
Press cake from Castor is poisonous and is mainly used as fuel and for fertilization. Detoxification methods have been developed to make press cake suitable as feed, but animals still do not like it, especially horses. [3]

5.2 Castor oil as a bio-fuel

5.2.1 Castor oil used as PPO (or SVO) as replacement for diesel

Factsheet Physical properties of castor oil in relation to diesel and other oils

Type of fuel/oil	**Specific gravity 20° C**	**Viscosity 20° C(Cst) (T in °C)**	**Pour point (°C)**	**Cloud point (°C)**	**Flash point (°C)**	**Iodine Number**	**Oil contents (% mass)**	**Conradson (% on total)**	**Cetane Number**	**LCV (Mj/Kg)**
Diesel fuel	0.81-0.84	4.6	-33	-15	52-102			0.01	43-52	42-53
RME	0.87-0.89									
coprah						10				
palm	0.92	60	22		280	45			39	36.9
cotton seed	0.92	50 (27)	-15.0	1.7	234	106		0,24	42-48	39.6
Jatropha	0.92	78.2	8	16	236	105	28-40	0.47	23-45	38-39
Ground nut	0.92	42 (37)	-7	13	282	93			42	
rape seed	0.91	78	-32	-4	285	105			37.6	37.6
castor	**0.95-0.97[1]**	**78 (300C)**	**-12-18 [3]**		**260**	**85**	**35-55**		**42 [1]**	**37-39 [1]**
soya	0.91	61	-12	-4	330	130			38	39.6
sunflower	0.92	58	-15	7	316	125			37.1	39.5



Viscosity as function of Temperature (Volkhard & da Silva, 2008)

So far, only a few experiments on the use of castor oil in diesel engines have been made. At the beginning of the1990s, castor oil was tested as pure plant oil (PPO) for engines in a laboratory of the German company Motorenwerke Bremerhafen AG. Due to the high cost of the oil or more precisely the lack of cost effectiveness of castor oil cultivation and extraction, these experiments were not continued. A careful assessment on the basis of these experiments shows that castor oil may possibly be appropriate for diesel engines suitable for vegetable oil.

Research on blending castor oil with diesel was performed by Naga Prasad et al in 2009 [2]. Conclusion of this research was that dilution of castor oil reduces the viscosity considerably. The blend containing 75% of diesel has viscosity 15 cSt close to viscosity of diesel at 30° C and does not require any heating prior to injection into the combustion chamber. Blends containing 50%, 25%, and 0% diesel require preheating up to 70, 80 and 95° C respectively. The performance and emission characteristics of 25% blend of castor is better than that of all other blends and it is comparable with diesel. Other blends included cotton seed oil and rice bran oils.

From the current experience it was concluded by Prasad that blends up to 25% without preheating and up to 50% with preheating can be substituted as fuel for diesel engine without any modifications in the engine. However, since no long term tests have been done and the oil quality is unknown, this conclusion is tentative and needs more research to be substantiated.

Long term endurance tests with diesel engines running on PPO of Castor needs to be done to evaluate if smooth operation of the engine is secured, or that certain parts might become damaged. See also the FACT Jatropha handbook, section 5. [26]

5.2.2 Biodiesel

From an energy point of view, Castor oil is the best vegetable oil for producing biodiesel (Castor methyl ester or Castor ME because it does not require heat and the consequent energy that is needed when other vegetable oils are transformed into biodiesel. Long storage times are unproblematic under airtight conditions. [28]

Biodiesel made from Castor oil still has a relatively high viscosity. In Brazil Castor ME was found too viscous to be used as such and is blended with biodiesel from other vegetable oils.

6 SUSTAINABILITY

Full LCA analyses from Castor for biodiesel production have not been undertaken, but energy balances are known however. Reported energy balances vary between 1.3:1 and 1:2. That means that energy used (to produce it) is about between 130% and 50% of that from fossil diesel. The spread in the values reported can be partly explained by differences in mechanization and use of inputs.

This also means that it is questionable if the minimally required 35% and later 50% greenhouse gas emission reduction, as required by the EU will be reached with bio-diesel from Castor.[3] The chances for this issue for PPO from Castor are somewhat better, since less energy and material inputs are required to produce it.

Castor is a crop that is mostly cultivated by small farmers. It can be grown on marginal land, and can be converted in PPO or biodiesel for local use. The economic viability depends in that case on various factors, such as high import (or transport) costs of fossil fuel, subsidies of castor bio-fuel compared to lower cost other fuels. For certain countries or regions, it might still be an attractive option to use Castor oil for bio-fuel. However with the present high price of castor oil (nearly double that of rapeseed oil), caused by its high value for bio-refinery into a large range of products, it is unlikely that castor oil will become a high volume feedstock for biodiesel or PPO. [3]

7 REFERENCES:

1. Volkhard Scholz, & Jadir Nogueira da Silva (2008) Prospects and risks of the use of castor oil as a fuel, Biomass and Bioenergy 32 (2008) pp. 95–100.
2. Performance and emission characteristics of a diesel engine with castor oil, Ch .S. Naga Prasad1 , K. Vijaya Kumar Reddy1, B.S.P. Kumar1, E. Ramjee1, O.D. Hebbel2 and M.C. Nivendgi2 1Dept. of Mech. Engg., JNTU College of Engg., Hyderabad-85; 2PDA College of Engg., Gulburga, Karnataka, India.
3. Wolter Elbersen, Leo Oyen, with contributions from: Rob Bakker and Rolf Blaauw "Nieuwe Grondstoffen voor Biobrandstoffen. Alternatieve 1e Generatie Energiegewassen" Report GAVE-09-01, SenterNovem.
4. Various Vegetable Oils as Fuel for Diesel and Burners: J.Curcas Particularities; G. Vaitilingom, A. Liennard, CIRAD-SAR, France
5. Jatropha oil in compression ignition engines, Thesis E. Rabé, TUe 2002
6. P. Tongoona, "Castor (Ricinus communis L.) research and production prospects in Zimbabwe," *Industrial Crops and Products* 1, no. 2-4 (December 1992): 235-239.
7. Reed 1976
8. S. D. Koutroubas, D. K. Papakosta, and A. Doitsinis, "Water Requirements for Castor Oil Crop (*Ricinus communis* L.) in a Mediterranean Climate," *Journal of Agronomy and Crop Science* 184, no. 1 (2000): 33-41.
9. Maroyi, A., 2007. **Ricinus communis** L. [Internet] Record from Protabase. van der Vossen, H.A.M. & Mkamilo, G.S. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. http://database.prota.org/search.htm. Accessed 1 April 2010
10. Carmen Leonor Barajas Forero, 2005, "Biodiesel from castor oil: a promising fuel for cold weather".
11. David T. Canvin, "Formations of oil in the Seed of *Ricinus communis* L.", Can. J. Physiol. Pharmacol. 41(9): 1879-1885 (1963),.
12. P. Tongoona, "Castor (Ricinus communis L.) research and production prospects in Zimbabwe," *Industrial Crops and Products* 1, no. 2-4 (December 1992): 235-239.
13. Dove BIOTech Ltd. 2005 "Castor Ben (*Ricinus* communis), an International Botanical Answer to Biodiesel Production & Renewable Energy"
14. Labalette, F., A. Estragnat, and A. Messéan. 1996. "Development of castor bean production in France." p. 340-342. In: J. Janick (ed.), Progress in new crops. ASHS Press, Alexandria, VA.
15. R.G. Shivas et al., "DISEASE NOTES OR NEW RECORDS: First record in Australia of Melampsora ricini on castor oil plant," *Austral. Plant Pathol.* 29, no. 2 (January 1, 2000): 150.
16. U. G. Akpan, A. Jimoh, and A. D. Mohammed "Extraction, Characterization and Modification of Castor Seed Oil from Leonardo Journal of Sciences,"
17. "National Non-Food Crops Centre - Castor," http://www.nnfcc.co.uk/metadot/index.pl?id=2629;isa=DBRow;op=show;dbview_id=2329.
18. ECOCROP, FAO "*Ricinus communis* L."
19. S. D. Koutroubas, D. K. Papakosta, and A. Doitsinis, "Water Requirements for Castor Oil Crop (*Ricinus communis* L.) in a Mediterranean Climate," *Journal of Agronomy and Crop Science* 184, no. 1 (2000): 33-41.
20. Luiz Pereira Ramos, 2008 "Biodiesel Production in South America" Congreso Latinoamericano de Qucongreso Química, Biofuels and Biobased Products Symposium July 29, 2008—San Juan, Puerto Rico
21. http://www.whc-oils.com/industrial-castor-oil.html
22. John W. Dunning Processing of Castor Beans, The VD Anderson Company, Cleveland, Ohio, 1953
23. Reports and conversation with Titus Galema, project leader Gota Verde project (www.gota-verde.org)
24. Philip Kokkelman, Report on filtration tests with castor oil, The Netherlands, July 19. 2009
25. Castor oil, by Bert Striegler
26. Jatropha Handbook, FACT, section 5.2.2
27. James A. Duke. 1983. Handbook of Energy Crops. Purdue University
28. Optimization of biodiesel production from castor oil , Nivea de Lima et al, University of Campinas, Brazil, 2006