Green Pesticides Handbook
Essential Oils for Pest Control

Leo M.L. Nollet, Hamir Singh Rathore

Castor Oil

Publication details
https://www.routledgehandbooks.com/doi/10.1201/9781315153131-18
R.T. Gahukar, Sheetal Mital
Published online on: 30 May 2017

18

Castor Oil

R.T. Gahukar and Sheetal Mital

CONTENTS

18.1 Introduction

Castor as an oil crop has gained importance in the global market, with its demand increasing annually by 3%–5% (Anjani 2012). This point is pertinent to recent development in the biodiesel feedstock supply, and of significant importance in the industrial production of pharmaceuticals. Therefore, the seed price is attractive for farmers who are inclined to cultivate castor crop in place of nonremunerative crops. Consequently, a lot of field research has been undertaken on oil extraction methods and the physicochemical properties for improving oil quality. As a pesticide, castor oil can be an ideal eco-friendly and cheap control measure against field pests and disease pathogens. Its use as medicinal product, however, needs intensive studies for human safety. Only a few studies have reported the isolation of essential oils from castor oil and their use compared with medicinal and aromatic plants. Thus, literature on this subject is scanty, and not easily available in compiled form. To close up this gap, the current review gathers information on the botany of the plant, compares oil extraction methods and physicochemical properties, and elaborates on oil utilization in crop and seed protection and also in pharmaceutical and industrial production. In Table 18.1, the local names for the castor bean plant used in different countries are given.

18.2 Botany of the Plant

The castor plant (castor bean or castor oil plant), *Ricinus communis* L., belongs to the family Euphorbiaceae (order Euphorbiales). The genus *Ricinus* is named after a Latin word for "tick," probably because its seed has markings and a lump at the end that resembles a certain tick. The origin of the plant is the Ethiopian region, but it has spread widely to East Africa, China, Thailand, South America, the Mediterranean basin, and India. Now, it is found throughout the world in tropical countries and a few temperate countries, where it is cultivated on a small scale as a border crop or as the sole crop on poor soils in semiarid zones, and it has become an abundant weed in the United States (Nangbes et al. 2013). It can grow well in all types of soil. However, well-drained soil with moisture retentive capacity, such as sandy loam soil, is ideal. It adapts to varied climates and grows fast even with a low availability of water and plant nutrients. However, insufficient nitrogen supply to plants results in reduced seed yield (Weiss 2000).

TABLE 18.1

Local Names for the Castor Bean Plant Used in Different Countries

Local Name	Country
Kerua, kerroa, charua	Arabia
Cherva, higuera del diablo infernal, tartago	Argentina
Bafureira, baga, carrapateira, mamona, mamono, ricino	Brazil
Pi ma, yuen kin tse, ta ma tse	China
Kai-dudu-deu	Cochin China
Higuerila	Costa Rica
Higuereta	Cuba
Ricin, bois de carapat, palma christi, paume dieu	France
Wunderbaum, ricinusol	Germany
Aporano	Ancient Greece
Kiki, kroton, mbacibo'	Modern Greece
Bupurura	Guinea Bisau (Manjaco tribe)
Buorai	Guinea Bisau (Biafada tribe)
Djague-djague	Guinea Bisau (Crioulo tribe)
Djacula	Guinea Bisau (Futa-Fula tribe)
Torra, entogai	Guinea Bisau (Balanta tribe)
Castor oilseed, palma christi, castor bean	Great Britain and the United States
Caffe da olio, erba da latte, erba lattaria, erba venaria, fagiolo d'india, fagiolo romano, fico d'inferno, girasole, girasole maggiore, girasole piccolo, mano aperta, meo, mirasole, palma christi, riccino, ricino, ricino comune, ricino minore, ricino volgare, scatapuzia, zecca	Italy
African coffee tree	Africa
Armanata	Falkland Islands
Higuerila, heguerilla, higuerillo, tartago, tlapatl	Mexico
Wonderolie	Holland
Tartago, castor	Paraguay
Higuereta	Dominican Republic
Ricinusa	Ancient Rome
Catoputia major	Russia
Eranda, erando, erumba, arand, erand, andi	India (Sanskrit)
Palma christi	Panama
Tartago	Venezuela

Source: U.S. Department of Agriculture, Natural Resources Conservation Service, *Ricinus communis* L. castor-bean, PLANTS Database, National Plant Data Center, Baton Rouge, 2006, http://plants.usda.gov; Rana, M. et al., *Int. J. Pharmtech. Res.*, 4(4), 1706–1711, 2012.

Castor is basically a long-day plant, but it is adaptable to various photoperiods (12–18 h) and pH values (4.5–8.3) (Salihu et al. 2014). Also, plants can tolerate a wide range of annual temperatures (7°C–27.8°C) and annual precipitation (20–429 cm) (Salihu et al. 2014). Because of its genetic characteristics, the plant greatly varies in its appearance and growth characteristics. For example, it may be a nonhardy fast-growing suckering perennial shrub, often developing into a small tree (12 m height), or a short-lived dwarf annual shrub. It is a common annual crop on marginal land and coastal sandy belts, where it can reach a height of 2–3 m and withstand even sandy and saline environments. The improved hybrids and varieties are generally dwarf plants that have been developed especially for high oil content.

18.2.1 Root

The tall plant has a well-developed taproot of a few meters, with substantial laterals and secondary roots. Roots of a dwarf plant reflecting a particular variety or cultural system show a less apparent root system. In low-rainfall areas, a poor root system is associated with slow aerial growth affecting overall plant development (Weiss 2000). A well-developed root system allows the plant to take maximum soil moisture and build plant resistance to drought. Also, it allows the plant to tap necessary nutrients for accumulating biomass, which is mostly correlated with yield performance (Weiss 2000). Therefore, planting castor in soft and loose soil (such as sandy loam) is advantageous for getting a better crop.

18.2.2 Stem

The stem is round in shape and red or purple in color, and sometimes covered with a waxy bloom that gives a red or green stem a blush appearance. In aged plants, the stem color turns to gray at the base. The stem has many branches, but only primary branches give rise to secondary branches, and this sequence is continued over the whole plant life. The stem of the dwarf plant remains solid, whereas in tall plant it becomes hollow after considerable height. The presence of plastids in the stem at the juvenile stage enhances the photosynthetic activity. Nodes are well developed, from each of which a leaf arises. The node at which the first racemes appear is a characteristic of quick maturity of the plant. In dwarf hybrids, it usually occurs after 6–12 nodes, but it can vary from 6 to 45 nodes in segregating populations (Weiss 2000).

18.2.3 Leaf

The leaf is large (about 10–60 cm long), often dark glossy green, light green, or reddish, with a long petiole. In some varieties, leaves start off as dark-reddish-purple or bronze when young, but gradually change to a dark green, sometimes with a reddish tinge as they mature. In other varieties, they are green from the seedling stage, whereas in still others, a pigment masks the green color of the chlorophyll-bearing parts (Weiss 2000). Leaf development and expansion is not affected by sunlight, but by soil moisture. Leaves are of a palmate type, with 5–11 lobes with toothed edges and prominent veins on the underside. They are alternate, except for two opposite leaves at the node immediately above the cotyledons (Weiss 2000).

18.2.4 Flower

Plants can produce flowers over a long period under favorable climatic conditions. Flowers are borne on inflorescences forming a pyramidal raceme or spikes on main and lateral branches. Flowers may be monoecious (male and female), pistillate (only female), or interspersed on the inflorescence. Male flowers are yellowish-green with prominent creamy stamens and are carried in void pikes up to 15 cm long. They are borne at the tips of the spikes to occupy the underportion of the spike with no corolla, but have a green calyx deeply cut into three to five segments enclosing numerous branched yellow stamens. Female flowers occupy the upper portion of the spike and likewise have no corolla (Weiss 2000). The three narrow segments of the calyx are reddish, and the ovary in the center is crowned by deeply divided red threadlike styles. There is wide variation between the flowers, the

ratio of male to female flowers, and the number of fertile female flowers. Female flowers have prominent stigmas and open before the male flowers in most of the varieties, while a reverse process occurs in others. Depending on the variety, the period of opening of female flowers, as well as that of male flowers, is 3–7 days (Weiss 2000). Generally, male flowers shed most of the viable pollens between 1 and 2 days after opening, and pollens shed from 2–3 h before sunrise to late afternoon, with a peak at midmorning. Pollen shedding is common in a temperature range of 26°C–29°C and relative humidity of 60%. Stigmas can remain receptive for a period of 7–10 days after opening (Weiss 2000).

18.2.5 Fruit

Fruit is a schizocarp globular spiny capsule with three cells, each of which splits open at maturity into separate parts and then breaks away explosively, shattering the seeds. Some varieties produce capsules with rudimentary spines, while others have soft, flexible, and nonirritant spiny capsules. However, some varieties produce spiny irritant capsules. After fertilization, a capsule is formed in 3–7 days. Racemes (indeterminate inflorescence) are conical, cylindrical, or oval with varied capsule arrangements, which can be compact, semicompact, or loose. The color of the capsule is mostly light green. The period of capsule maturity varies from 140 to 160 days depending on the variety (Weiss 2000). The lowest flowering racemes usually mature first; the others follow in sequence up to the stem. Ripening of fruits along the racemes is sometimes uneven in some wild varieties, and the period between the first and last mature fruits may be several weeks.

When ripe, capsules become hard and brittle and shatter mostly at maturity. In some varieties, the whole capsule falls from a desiccated raceme, with the seed remaining enclosed, or the capsule may split to release seeds (Weiss 2000). Strong capsules tend to preclude mechanical hulling, while very soft capsules become difficult to hull without damaging seeds (Salihu et al. 2014).

18.2.6 Seed

The castor seed has warty appendages called "caruncle," which is a type of elaiosome (fleshy structures attached to seeds). The caruncle promotes the dispersal of the seed. The seed is elongated, oval, or square, covered with thin, brittle, and mottled testa enclosing a white kernel of varied length (up to 250 mm) and breadth (5–15 mm). Seed color varies considerably; for example, it can be white, dark brownish–red, brown, dark chocolate, red, or black. The seed weight varies from 9 to 100 g for 100 seeds, depending on the number of seeds produced. The period of dormancy extends to several months in some varieties, while some seeds can be sown with normal germination after harvest. Dormancy can be broken by soaking seeds for 2 h in water or by removing the caruncle and piercing testa at the side. Germination is epigeal, with cotyledons coming out above the soil, expanding as green leaves (Weiss 2000). Bigger seeds germinate earlier than the smaller seeds.

18.3 Seed Oil

Castor oil is composed of 0.7% moisture, 48.8% fat, 7.2% protein, 11.6% carbohydrates, and 10.6% ash (Mbah et al. 2014). Several phytochemicals, such as cineole, 2-octanol,

terpene-4-ol, limonene, subinene, pinene, terpinene, and the methyl groups tannin, phenol, alkaloid, oxalate, phytate, saponin, cyanogenic glycoside, and flavonoid, have been isolated or extracted, and only tannin is abundant (0.35%) (Momoh et al. 2012). Also, five types of triacylglycerols have been identified by Salimon et al. (2010) in castor oil from Malaysia: triricinolein (84.1%), diricinoleoylstearoylglycerol (8.2%), diricinoleoyloleoylglycerol (5.6%), diricinoleoyllinoleoylglycerol (1.2%), and diricinoleoylpalmitoylglycerol (0.9%). Castor oil is rich in triglycerides, mainly ricinolein and ricin (water-soluble toxin). Castor oil has the following unique properties.

1. It is colorless to very pale yellow, and tasteless or with mild taste.
2. Ricinoleic acid in castor oil is highly unusual because of its unique hydroxyl fatty acid ($C_{18}H_{34}O_3$), structurally known as cis-12-hydroxyoctadeca-9-enoic acid, with 18-carbon hydroxylated fatty acid having one double bond that is composed of triglycerides (esters) containing a 3-carbon alcohol (glycerol) and three 18-carbon (or 16-carbon) fatty acids (Ogunniyi 2006). Cvengros et al. (2006) showed that the hydroxyl group of ricinoleic acid affects the density and viscosity of the oil. No other commercial seed oil has such a high predominance of a single fatty acid with a high energy value and biofuel potential.
3. Oil uniformity and consistency, and comparatively, its high specific gravity, are important properties for its industrial use.
4. It is nontoxic and biodegradable, with a high oxidative stability of 44 h and a low cloud point of –14°C (making it useful even in cold weather) and can be stored up to 1 year if refrigerated (Abdelaziz et al. 2014).
5. Its easy solubility in alcohols at room temperature and limited solubility in aliphatic petroleum solvents facilitate several chemical reactions.
6. It is the most promising renewable raw material for the chemical and polymer industries.
7. It has a low energy requirement for oil production, for example, 56.8 GJ/ha. Castor seed consumes only 19% of the total energy, whereas 39% of energy is consumed in oil extraction and refining and 42% in biodiesel production (Severino et al. 2012).
8. Castor oil differs from other oils with its acetyl or hydroxyl value and comparatively high viscosity, making it an excellent emollient and lubricant (lubricity as low as 2g/kg) over a wide range of temperatures, and it has the capacity to wet and disperse rapidly.

18.4 Methods of Oil Extraction

Three methods of oil extraction have been used by various researchers and villagers. Among these, chemical extraction is common, particularly in industrial production.

18.4.1 Wet Extraction

In Nigeria, wet extraction is popularly employed as tradition by women, with only a 19% oil yield (Oluwole et al. 2012). In this method, castor beans are crushed and oil is extracted

by using hot water or steam. This method, although economical, is not effective, and therefore extensive research is needed for its improvement and validation so that resource-poor villagers will be able to use it efficiently.

18.4.2 Mechanical Extraction

In this process, mechanical compressors, including the hydraulic press and continuous screw press, are employed to extract oil at room temperature. Some modifications by increasing the temperature or cold press have also been tested. A general method used by Perdomo et al. (2013) is described below.

A sample of 200 g of castor seeds is placed in a mechanical extruder. Seeds are compressed with the hydraulic press for 2 min at a pressure of 490 kPa, and then to 748 kPa for 2 min. Later, the cake is reused and the process is repeated. Extracted oil is centrifuged twice for 16 min at 1300 revolutions per minute (rpm) in order to clean the oil and remove suspended solids.

18.4.3 Chemical (Soxhlet) Extraction

18.4.3.1 Processing

Before extraction, castor seeds are processed to get the maximum yield of quality oil. The preliminary operations include cleaning, drying, dehulling, winnowing, and grinding. By handpicking or using a sieve, castor seeds are cleaned and separated from foreign materials such as dirt. Cleaned seeds are packed in net bags and dried in a greenhouse (Perdomo et al. 2013) or sun-dried for 4–5 days in the open until the shells split and the seeds shed. In order to further reduce the moisture content, seeds are dried in an oven at 60°C for 7 h (Akpan et al. 2006), 90°C for 6 h (Mgudu et al. 2012), 95°C for 7 h (Perdomo et al. 2013), or 105°C for 1 h (Salimon et al. 2010). These seeds are put in a desiccator for about 30 min, removed, and reweighed every 2 h until a constant weight is obtained.

Moisture content in seeds can be affected by plant morphology, specific biomass composition, seed immaturity, and conditions of seed storage (Perdomo et al. 2013). In any case, low moisture content in extracted oil is an indicator of good shelf life (Abitogun et al. 2008). The moisture content in seeds is calculated per the following formula: (W1 – W0)/W0 × 100, where W1 and W0 are the initial weight before drying and final weight after drying, respectively. The winnowing is done in the tray to blow away seed cover. The cleaned seeds are then ground by using hand machines or simply crushed with a mortar and pestle into a paste or cake to make extraction easy and rapid.

18.4.3.2 Extraction

Researchers used different methods to extract oil with chemical solvents in a Soxhlet apparatus. A common method and modifications are described below.

A solvent is poured into a round-bottom flask in which paste is placed and then inserted in the center of the extractor inside the heating mantle. A condenser is connected to the extractor. The Soxhlet is heated at 60°C, and when solvent boils, the vapor rises through the vertical tube into the condenser at the top. The condensed liquid drips on a filter paper thimble. The extract seeps through the pores of the thimble and fills the siphon tube, where it flows back down into the round-bottom flask. This operation takes around 30–45 min. The extract is removed from the tube, dried in the oven, and cooled in the desiccator.

This operation is repeated several times to get the desired quantity of oil. At the end of the extraction, the resulting mixture containing the oil is heated at 70°C to recover or remove solvent from the oil, and the percentage of oil extracted is determined. The solvent can also be evaporated using a rotary evaporator (Salimon et al. 2010).

Oil can be extracted by various chemical solvents (hexane, cyclohexane, ethyl acetate, methanol, isopropanol, ethanol, pentane, and petroleum ether). Among them, ethyl acetate and methanol have been extensively used with oil contents of 56.0% and 55.2%, respectively (Dasari and Goud 2014). Meneghetti et al. (2006) reported that biodiesel can be obtained by transesterification of castor oil with either ethanol or methanol, with a similar yield of fatty acid esters; however, methanol as a transesterification agent is rapid. Methanol as a solvent and sodium hydroxide as a catalyst can replace ethanol and potassium hydroxide, respectively (Dasari and Goud 2014). Also, despite the high moisture content, great reduction in viscosity is possible with the transesterification reaction (Thomas et al. 2013). Recently, Compton et al. (2015) suggested solvent-less esterification with ferulic acid. The feruloytated oil is a ultraviolet (UV) (280–361 nm) absorbent and antioxidant, and therefore can be a potential candidate for incorporation into lipid bilayers to protect liposomes and their contents from reactive oxygen species. Similarly, a liquid industrial waste from distillery (known as feint) can be an effective bioresource substitute for commercial solvents for the extraction of oil used in resin production (Akartha and Anusiem 1996). Conclusively, mechanical extraction (hot pressing using a hydraulic press), followed by chemical extraction (solvent), is common. Oil extracted (%) is calculated as (oil/sample size) × 100 (Akpan et al. 2006; Mgudu et al. 2012). The difficulty is that even with the same method used by several researchers, there is still a difference in oil yield, which is attributed to use of immature seeds and different conditions of seed storage (Meneghetti et al. 2006).

The data of two extraction methods are shown in Table 18.2. With mechanical extraction, a higher content of 49.8% of free fatty acids (FFAs) was obtained compared with wet extraction (vs. 33.4%), but the content of ricinoleic acid was less (64.81%) in mechanical extraction than in chemical extraction (76.06%). Viscosity is much higher with mechanical extraction at room temperature (Perdomo et al. 2013). Density becomes important for estimating the production cost and process design for large-scale industrial production of castor oil. Generally, the density of extracted oil is a little greater with mechanical extraction than with chemical extraction (Table 18.2). Otherwise, the oil yield obtained by Soxhlet extraction is 1.5 times greater than that obtained by mechanical extraction. Since relative

TABLE 18.2

Effect of Two Extraction Methods on Oil Yield, Content of Fatty Acids, and Oil Density

Content/Method	Soxhlet Extraction	Mechanical Extraction (Room Temperature)	Mechanical Extraction (60°C)
Oil yield (%)	40.175–56.218	–	26.314–36.597
Free fatty acids (%)	0.0291–0.0557	0.0272–0.1504	0.0420–0.0950
Palmitic acid (%)	0.15	0.30	0.22
Stearic acid (%)	1.03	6.42	10.16
Oleic acid (%)	1.39	4.61	3.80
Linoleic acid (%)	9.17	23.28	1.75
Linolenic acid (%)	0.36	0.58	0.16
Ricinoleic acid (%)	76.06	64.81	83.99
Density (g/cm^3)	0.931–0.949	–	0.956–0.958

Source: Perdomo, F.A. et al., *Curr. Sci.*, 110(10), 1890–1892, 2013.

solubility and solvent chemical affinity are important factors in the extraction process, chemical extraction results in cleaner oil, as solvent hexane is washed out during processing. If the cold-press method is used in mechanical compression, oil has a low acid value and iodine value, with lighter color, and a high saponification value compared with Soxhlet-extracted oil (Okullo et al. 2012).

18.5 Refining of Extracted Oil

Refining is needed to improve certain oil properties. For example, there is a reduction at high temperature in the viscosity, peroxide value, acid value, saponification value, and iodine value, and an increase in the pour point (Table 18.3). Generally, viscosity is reduced after a transesterification reaction, irrespective of the initial high viscosity and high moisture content (Akpan et al. 2006; Thomas et al. 2013). After removing stones and other impurities, clay is ground and mixed with water. To activate, 2 M HCl is added to the clay and the mixture is boiled at 100°C for 2 h. The mixture is washed with water and then dried and ground (Akpan et al. 2006). The extracted oil is degummed by adding boiling water, and the mixture is stirred for 2 min and allowed to stand in the separating funnel. The aqueous layer is removed and the procedure is repeated until all gum is removed (Akpan et al. 2006). The next step is neutralization. For this process, 60 g of degummed oil is poured into a beaker and heated to 80°C, after which 40 ml of 0.1 M NaOH is added and stirred to a uniform solution. Sodium chloride is added at 10% (w/w) so that formed soap settles down. This material is transferred into a separating funnel and allowed to stand for 1 h. Soap is separated from the oil, and hot water is added again and again to the oil solution until soap is fully removed. Neutralized oil is then drawn off into a beaker (Akpan et al. 2006).

TABLE 18.3

Certain Properties of Crude Oil and Refined Oil

	Nigeria		Sudan	
Oil Properties	**Crude**	**Refined**	**Crude**	**Refined**
Viscocity at 28°C	9.424	6.484	–	–
Viscocity at 40°C	–	–	234.0	209.6
Viscocity at 100°C	–	–	18.79	18.30
Ester value	–	–	178.09	177.65
Peroxide value	–	–	6.93	5.90
Pour point (°C)	–	–	5.0	7.0
pH	6.11	6.34	–	–
Acid value (mg of NaOH/g of oil)	1.148	0.869	1.231	0.916
Saponification value (mg of KOH/g of oil)	185.83	181.55	179.33	178.56
Iodine value (g of I_2/100 g of oil)	87.72	84.8	86.98	84.23
Specific gravity	–	–	0.963	0.960

Source: The Nigeria data are from Akpan, U.G. et al., *Leonardo J. Sci.*, 8, 43–52, 2006. The Sudan data are from Abdelaziz, A.I.M. et al., *J. Chem. Eng.*, 2(1), 1–4, 2014.

For bleaching, 50 g of neutralized oil is poured into a beaker and heated to 90°C. Activated clay is added at 15% (w/w), and the mixture is stirred continuously for 30 min until the temperature rises to 110°C for another 30 min. The whole content is filtered hot in an oven at 70°C (Akpan et al. 2006; Abdelaziz et al. 2014). Further, to obtain pure oil, 20 g of oil is warmed at 35°C and 15 ml of concentrated sulfuric acid (98% pure) is added. The mixture is allowed to react with constant stirring, and then is washed with hot distilled water and left to stand for 2 h, after which water is removed and the sulfuric acid ester formed is finally neutralized with 10 ml of 0.1 M sodium hydroxide (Akpan et al. 2006). After refining and bleaching, oil becomes colorless or slightly yellowish, from the original pale straw color.

Equally important for industrial use are the various reactions of castor oil and characteristics of oil grades (Tables 18.4 and 18.5).

TABLE 18.4

Various Reactions of Castor Oil

	Nature of Reaction	Added Reactants	Type of Products
Ester linkage	Hydrolysis	Acid, enzyme, or Twitchell reagent catalyst	Fatty acids, glycerol
	Esterification	Monohydric alcohols	Esters
	Alcoholysis	Glycerol glycols, pentaerythritol, and other compounds	Mono- and diglycerides, monoglycols, etc.
	Saponification	Alkalies, alkalies plus metallic salts	Soluble soaps, insoluble soaps
	Reduction	Na reduction	Alcohols
	Amidation	Alkyl amines, alkanolamines, and other compounds	Amine salts, amides
Double bond	Oxidation, polymerization	Heat, oxygen, cross-linking agents	Polymerized oils
	Hydrogeneration	Hydrogen (moderate pressure)	Hydroxystearates
	Epoxidation	Hydrogen peroxide	Epoxidized oils
	Halogeneration	Cl_2, Br_2, I_2	Halogenated oils
	Addition reactions	S, maleic acid	Polymerized oils, factice
	Sulfonation	H_2SO_4	Sulfonated oils
Hydroxyl group	Dehydration, hydrolysis, distillation	Catalyst (plus heat)	Dehydrated castor oil, octadecadienoic acid
	Caustic fusion	NaOH	Sebacic acid, capryl alcohol
	Pyrolysis	High heat	Undeclenic acid, heptaldehyde
	Halogenation	PCl_5, $POCL_3$	Halogenated castor oils
	Alkoxylation	Ethylene and/or propylene oxide	Alkoxylated castor oils
	Esterification	Acetic, phosphoric, maleic, and phthalic anhydrides	Alkyl and alkylaryl esters, phosphate esters
	Urethane reaction	Isocyanates	Urethane polymers
	Sulfation	H_2SO_4	Sulfated castor oil (Turkey red oil)

TABLE 18.5

Characteristics of Castor Oil Grades

Properties	Cold-Pressed Oil	Solvent-Extracted Oil	Dehydrated Oil	Methanol-Extracted Oil
Specific gravity	0.961–0.963	0.957–0.963	0.926–0.937	0.961
Acid value	3	10	62	0.91
Iodine value (Wij)	82–88	80–88	125–145	89
Saponification value	179–185	177–182	185–188	185

18.6 Methods of Oil Analysis for Physicochemical Properties

This is a very important aspect of castor oil for its utilization. Therefore, intensive research has been undertaken on the extraction and characterization of castor seed oil in tropical countries, particularly Brazil (Conceicao et al. 2007), India (Sridhar et al. 2010), Malaysia (Salimon et al. 2010), Mexico (Perdomo et al. 2013), Nigeria (Akpan et al. 2006; Abitogun et al. 2008; Nangbes et al. 2013), Pakistan (Chakrabarti and Ahmad 2008), Sudan (Abdelaziz et al. 2014), and South Africa (Mgudu et al. 2012).

Different methods have been used, the most common being those recommended by the Association of Official Analytical Chemists, British Pharmacopoeia, and American Society for Testing and Materials (ASTM). Stubiger et al. (2003) found that the techniques of high-performance liquid chromatography (HPLC) and mass spectrometry (MS) are satisfactory for detecting and quantifying fatty acids. Later, Cvengros et al. (2006) suggested vapor pressure osmometry (VPO) to determine molecular weight accurately. General methodologies for studying the physicochemical properties of castor oil are discussed below.

18.6.1 Acid Value

This is the quantity of potassium hydroxide expressed in milligrams that is needed to neutralize the acidic constituents or free fatty acids in a gram of castor oil. Diethyl ether and ethanol, 25 ml each, are mixed in a 250 ml beaker. This mixture is added to 10 g of oil in a 250 ml conical flask, and a few drops of phenolphthalein are added to the mixture, which is titrated with 0.1 M NaOH to the end point with continuous shaking until the mixture becomes dark pink. An increase in acid value is due to hydrolysis of triacylglycerol (an important aspect for long shelf life of castor oil). The acid value is calculated as 2× the free fatty acid value (Akpan et al. 2006; Mgudu et al. 2012).

18.6.2 Color

Generally, the color of castor oil is determined by using a lovibund tintometer and half-inch cell. The pale-yellow color is generally attributed to the low acid value (Mgudu et al. 2012).

18.6.3 Fatty Acid Profile

The fatty acid profile is important because of the dependence of biodiesel properties on the structure and type of fatty acid alkyl esters. This profile can be used to check the level of oxidative deterioration of the oil by enzymatic and chemical oxidation. For example,

heating (Soxhlet extraction or mechanical extraction at 60°C) increases the FFA percent, and thereby the acid value, compared with extraction done at room temperature (Table 18.6). Perdomo et al. (2013) quantified free fatty acid content by taking 100 µl of acid and mixing with 1 ml of NaOH methanolic solution. Oil samples are heated to 100°C for 25 min, and 6 ml of HCl methanolic solution is placed into the solution and heated again up to 80°C for 10 min, followed by the addition of 3.75 ml of an equimolar hexane–methyl tert-butyl ether solution. The upper phase is removed and mixed with 9 ml of NaOH solution, and its volume is measured. Fatty acids are analyzed by using a HP 5890 gas chromatograph equipped with software. The identification of peaks is performed by comparing the

TABLE 18.6

Physicochemical Properties of Castor Oil from Different Provenances

Parameters	Malaysia	Pakistan	Sudan	Nigeria (Plateau State)	Nigeria (Osun State)	ASTM
Acid value (mg NaOH/g of oil)	4.9	–	0.916	14.8	14.8	0.4–4.0
Color (unit)	–	–	–	14.00	14.00	–
Congealing temperature (°C)	–	–	–	–	–18	–21.7
Copper corrosion (1–3 scale, 3 being corrosive)	–	–	–	–	1	–
Density (g/cm^3, 20°C)	–	0.9584	–	0.948	–	–
Ester value	–	–	177.6	–	–	–
Fire point (°C)	–	–	–	256	256	–
Flash point (°C)	–	310	305	225	225	320
Free fatty acids (%)	3.4	–	–	7.4	7.4	0.3–2.0
Iodine value (mg/g)	84.5	–	84.2	58.64	58.39	82–88
Lipid content (%)	43.3	–	–	–	–	–
Moisture content (%)	0.2	–	–	0.30	0.30	3.16–3.72
Molecular weight	937.7	–	–	–	–	–
pH	–	–	–	5.8	5.8	–
Peroxide value (mEq/kg)	–	–	5.9	158.6	178.0	–
Refractive index (25°C–30°C) (20°C–25°C)	1.47	–	–	1.792	1.792	1.476–1.179
Saponification value (mg KOH/g oil)	182.9	–	178.6	180.77	178.0	175–187
Smoke point (°C)	–	–	–	215	215	–
Specific gravity (29°C–25°C)	–	–	0.96	–	0.948	0.957–0.968
Tert-butyl nitrite	–	–	0.34	–	–	–
Turbidity (Jackson turbidity unit)	–	–	–	5.0	5.0	–
Viscocity (mm^2/s, 25°C)	–	–	–	–	–	6.3–6.8
Viscocity (mm^2/s, 40°C)	332	239	209	0.425	0.425	240.12

Source: The Malaysia data are from Salimon, J. et al., *Sains Malaysiana*, 39(5), 761–764, 2010. The Pakistan data are from Chakrabarti, M.H., and Ahmad, R., *Pak. J. Bot.*, 40(3), 1153–1157, 2008. The Sudan data are from Abdelaziz, A.I.M. et al., *J. Chem. Eng.*, 2(1), 1–4, 2014. The Nigeria (Plateau State) data are from Nangbes, J.O. et al., *Int. J. Eng. Sci.*, 2(9), 105–109, 2013. The Nigeria (Osun State) data are from Abitogun, A. et al., *Internet J. Nutr. Wellness*, 8(2), 2008.

retention times with standard methyl ricinoleate and other fatty acid methyl esters. The lower content of FFA is generally a result of impurities in crude oil.

Mgudu et al. (2012) used another method. A mixture of 12.5 ml of diethyl ether + 12.5 ml of ethanol is taken in a beaker and 5 g of oil is in a conical flask. A few drops of phenolphthalein are added. The mixture is titrated with 0.1 M NaOH with constant shaking until a dark pink color appears. A volume of 0.1 M NaOH is noted. Here, 100 ml of 0.1 M NaOH is equal to 2.83 g of oleic acid. They proposed a formula for calculating the percentage of fatty acid content (%) as (Vo/Wo) × 2.83 × 100, where Vo is the volume of 0.1 M NaOH (100 ml of 0.1 M NaOH = 2.83 g of oleic acid) and Wo is the sample weight.

18.6.4 Iodine Value

This value is the measure of the degree of unsaturation. The method used by Akpan et al. (2006) is described for estimating iodine value. An oil sample of 0.4 g is weighed in a conical flask, and 20 ml of carbon tetrachloride is added to dissolve the oil. Then, 25 ml of Dam's reagent is added to the flask using a safety pipette in a fume chamber. The content is vigorously stirred after putting a stopper in the flask and placing it in the dark for 2 h, 30 min. At the end of the period, 20 ml of 10% aqueous potassium iodide and 125 ml of water are added using a measuring cylinder. The content is titrated with 0.1 M sodium thiosulfate solution until the yellow color disappears. A few drops of 1% starch indicator are added, and the titration is continued by adding thiosulfate drops until the blue coloration disappears after vigorous shaking. The same procedure is used for a blank sample and the iodine value is calculated as 12.69C(V1 – V2)/M, where C is the concentration of sodium thiosulfate, V1 is the volume of sodium thiosulfate used for the blank, V2 is the volume of sodium thiosulfate used for determination, and M is the mass of the sample.

18.6.5 Value of pH

Mgudu et al. (2012) proposed a method in which 2 g of oil is poured into a clean dry beaker and 13 ml of hot distilled water is added. The mixture is stirred slowly and then cooled in a cold water bath to 25°C. The pH electrode is first standardized with a buffer solution and then submerged into the oil–water mixture. The formula for estimating the pH was not given by these researchers.

18.6.6 Refractive Index

This value is an indication of the level of saturation of the oil. A few drops of the sample are transferred into the glass slide of the refractometer coupled with a thermometer, calibrated specimen, and light source. Water at 30°C is circulated around the glass slide to keep a uniform temperature. Through the eyepiece of the refractometer, the dark portion viewed is adjusted to be in line with the intersection of the cross. At no parallax error, the pointer on the scale points to the refractive index. This procedure is repeated and the mean value is recorded as refractive index (Akpan et al. 2006).

18.6.7 Saponification Value

Akpan et al. (2006) described the following method of saponification. In a conical flask, 2 g of cake + 25 ml of 0.1 N ethanolic potassium hydroxide are taken. This mixture is boiled gently for 60 min with continuous stirring. A reflex condenser is placed on the flask

containing this mixture, and a few drops of phenolphthalein indicator are added to the warm solution and then titrated with 0.5 M HCl to the end point until the pink color of the indicator disappears. The same procedure is followed for a blank test. The formula for calculating the saponification value is 56.1 N(V0 – V1)/M, where V0 is the volume of the solution used for the blank test, V1 is the volume of the solution used for determination, N is the actual normality of HCl used, and M is the mass of the sample.

18.6.8 Specific Gravity

A clean and dry-density bottle or conical flask of 25 ml capacity is weighed and then filled in with 10 ml of oil. After inserting a stopper, the bottle is reweighed (W1). Oil is substituted with water after washing and drying the bottle, and weighed (W2). The formula proposed by Akpan et al. (2006) and Mgudu et al. (2012) is Sp. gr. = (W1 – W0)/W2 – W0 = mass of the substance/mass of an equal volume of water.

18.6.9 Triacylglycerols

Salimon et al. (2010) used high-performance liquid chromatography. The mobile phase was acetone–acetonitrile (63.5:36.5), and the flow rate, column temperature, detector temperature, and analysis time were 1 ml/min, 30°C, 40°C, and 30 min, respectively. Oil samples (2 ml containing 0.1 ml of oil dissolved in mobile phase solvent) were injected, and each peak was identified by comparing it with the standard sample based on the equivalent carbon number.

18.6.10 Viscosity

For estimating oil viscosity, Akpan et al. (2006) have proposed a rapid system. A clean, dry viscometer with a flow time above 200 s for the fluid is used. The sample is filtered through a fine mesh screen to eliminate dust and other solid material. The viscometer is charged with the sample by inverting the tube in the thinner arm into the liquid sample, and suction force is drawn up to the upper timing mark of the viscometer, after which the instrument is tuned to its normal vertical position. The meter is placed into a holder and inserted into a constant temperature bath at 29°C; about 10 min is allowed for the sample to reach the bath temperature of 29°C. The suction force is then applied to the thinner arm to draw the sample slightly above the upper timing mark. The afflux time is noted by timing the flow of the sample from the upper mark to the lower mark.

Perdomo et al. (2013) used a VM 3000 Stabinger viscometer at 40°C and 5 ml of oil sample and reported fourfold greater viscosity with mechanical extraction at room temperature than with mechanical extraction at 60°C or chemical extraction. The greater value is generally due to suspended particles present in the crude oil.

18.7 Comparison of Physicochemical Properties from Different Provenances

Data for some important physicochemical properties of refined oil from four countries and those recommended by ASTM are given in Table 18.6. The properties differ considerably from one country to another country, and from one region to another region within

a country. Besides, the factors affecting seed quality, methods used for oil extraction, and methods for estimating physicochemical properties are major contributing factors for this variation. Therefore, standardization of these methods is needed for making oil marketable at a cheaper rate than petroleum-based fuels. Since the data on properties are often fragmentary, comparison is difficult and recommendations cannot be made. However, it gives an idea of content from different geographic origins. It is also useful to improve these properties in order to bring them closer to the standard of ASTM.

18.8 Factors Affecting Oil Content and Physicochemical Properties

18.8.1 Cultural Practices of Castor Cultivation

In India, delayed sowing was found to be promising with respect to oil quality characteristics and fatty acid composition. On the other hand, the content of ricinoleic acid was not influenced by the date of sowing. Higher oil content under dry cultivation than in irrigated fields has been reported (Ramanjaneyulu et al. 2013). In Egypt, castor cultivation with foliar spraying of K-amino fertilizers, irrigations (75% of water requirement), and/or 100% of the water evapotranspiration regime was found appropriate to produce maximum oil (Mohammed and Mursey 2015). These examples show that suitable cultural practices can be one of the factors for high oil content in castor plants, although these criteria may differ in each crop-growing area.

18.8.2 Castor Genotypes

In Brazil, Ramos et al. (1984) surveyed 36 castor varieties with a large variability in oil content and fatty acid composition. Similarly, 11 genotypes in Mexico (Armendaziz et al. 2015) and 31 genotypes in India (Kallamadi et al. 2015) were tested for oil content with wide variation. Perdomo et al. (2013) analyzed oil extracted from seven cultivars from Queretaro state alone in Mexico and reported minimum and maximum oil contents of 31.5% and 56.21%, respectively. The content of fatty acids also varied considerably, for example, palmitic acid (0.00%–0.41%), stearic acid (0.04%–1.58%), oleic acid (0.32%–2.08%), linoleic acid (1.9%–21.69%), linolenic acid (0.05%–0.86%), and ricinoleic acid (74.68%–95.49%). A natural mutant with a high content of oleic acid (cv. A-74) and another mutant with a low content of ricinoleic acid (cv. OLE-1) showed great potential for castor oil content (Velasco et al. 2005). In both cultivars, there was a 10% increase in oil at plant maturity, with no difference in the content of palmitic, linoleic, and linolenic acids (Velasco et al. 2005). Ricinoleic acid content raised to >80% at 21 days after pollination in one mutant and to 75% at 78 days in another mutant. However, the content of gamma-tocopherol was similar in both cultivars and alpha-, beta-, and delta-tocopherol raised at maturity to 605–785 mg/kg of dry seeds (Velasco et al. 2005). The acid value (0.66%–3.88%) and saponification values (166.5%–195.2%) differed significantly among local cultivars from Nigeria, whereas the iodine value, specific gravity, viscosity, refractive index, pH, and peroxide value did not differ among cultivars (Oluwole et al. 2015).

Several methods, including genetic markers, *in vitro* propagation, and genetic transformation, have been successfully exploited to screen cultivars for obtaining high oil yield (Singh et al. 2015). Genetic diversity can also be assessed with a dendogram prepared with

the help of simple sequence repeat (SSR) and amplified fragment length polymorphism (AFLP) (Pecina-Quintero et al. 2013). These techniques are useful to breed and select cultivars with desired traits of high oil content from local, regional, or national-level collections. Currently, there are 50 gene banks of castor genotypes across the world (Anjani 2012), which facilitate exchange and distribution of seed for different countries.

18.8.3 Geographical Origin

Each region has its own characteristic features, such as climate, soil, crop cultivation practices, and varietal preference. Therefore, oil content differs considerably from one country to another, for example, 33.4%–49.8% in Mexico (Perdomo et al. 2013), 32% in Sudan (Abdelaziz et al. 2014), 43.69%–52.78% in Tanzania (Omari et al. 2015), 35%–46% in Iran (Alizeralu et al. 2011), and 48% in Nigeria (Abitogun et al. 2008). There is wide variation in physiochemical properties among oils from different countries, for example, acid value (0.44–1.97 mg NaOH/g), free fatty acids (0.22%–0.99%), peroxide value (10.87–13.73 mEq/g), saponification value (165.5–187.5 mg/KOH/g), iodine value (78.15–83.42 g of I_2/100 g), specific gravity (0.945–0.985), refractive index (1.468–1.473), pH (5.7–6.3), and viscosity (9.0–9.3) for oil from Nigeria (Abitogun et al. 2008), and moisture content (0.3%–1.2%), refractive index (1.404–0.430), saponification value (164–179 mg KOH/g), acid value (0.2–0.9 mg NaOH/g), iodine value (75–86 g of I_2/100 g), and peroxide value (0–0.5 mEq/kg) for oil from Iran (Alizeralu et al. 2011).

In the case of fatty acids, Table 18.7 shows that a higher content (>90%) of the main component (ricinoleic acid) is from Brazil, Pakistan, and Tanzania. The exchange of seeds of castor genotypes with great oil potential should therefore be encouraged.

18.8.4 Temperature of Extraction

According to Canvin (1965), the temperature of chemical extraction does not have any effect on the oil content and fatty acid composition. On the contrary, temperature did affect these contents in mechanical extraction. For example, Perdomo et al. (2013) reported an oil

TABLE 18.7

Content (%, w/w) of Fatty Acids in Castor Oil from Five Countries

Fatty Acid	Malaysia	Brazil	Pakistan	Nigeria (Plateau State)	Nigeria (Osun State)	Tanzania (6 Regions)
Linoleic	7.3	4.4	4.4	0.61	0.61	2.9–4.8
Linolenic	0.5	0.2	0.2	0.33	0.30	–
Olei	5.5	2.8	2.8	2.28	2.28	1.4–5.1
Palmitic	1.3	0.7	0.7	0.46	0.46	2.3–4.8
Ricinoleic (of total acids)	84.2	90.2	90.2	83.97	81.94	83.5–92.3
Stearic	1.2	0.9	0.9	0.52	0.50	1.1–4.2
Saturated acids	2.5	1.6	–	–	–	3.8–11.7
Unsaturated acids	97.5	97.6	–	–	–	88.3–96.2

Source: The Malaysia data are from Salimon, J. et al., *Sains Malaysiana*, 39(5), 761–764, 2010. The Brazil data are from Conceicao, M.M. et al., *Renew. Sustain. Energy Rev.*, 11, 964–975, 2007. The Pakistan data are from Chakrabarti, M.H., and Ahmad, R., *Pak. J. Bot.*, 40(3), 1153–1157, 2008. The Nigeria (Plateau State) data are from Nangbes, J.G. et al., *Int. J. Eng. Sci.*, 2(9), 105–109, 2013. The Nigeria (Osun State) data are from Abitogun, A. et al., *Internet J. Nutr. Wellness*, 8(2), 2008. The Tanzania data are from Omari, A. et al., *Green Sustain. Chem.*, 5(4): 154–163, 2015.

content of 40.17%–56.22% in chemical extraction and a lower quantity (26.31%–36.595%) in mechanical extraction, even at 60°C. A greater content at 60°C of stearic acid (10.16% vs. 6.42% at room temperature) and ricinoleic acid (83.99% vs. 64.81% at room temperature), and a smaller amount of palmitic acid (0.30% vs. 0.22% at room temperature), oleic acid (4.61% vs. 3.8% at room temperature), linoleic acid (1.75% vs. 23.28% at room temperature), and linolenic acid (0.16% vs. 0.58% at room temperature), has been reported by Perdomo et al. (2013). Similarly, a maximum oil yield of 41.67% (oil recovery of 75.76%) from crushed seed was obtained at 90°C and 135 kPa for a pressing time of 12 min (Olaniyan 2010). Better oil recovery is the effect of temperature inducing a rupture in triacylglycerols in the oil and generating a rise in free fatty acids and diacylglycerols (Perdomo et al. 2013). Oil viscosity decreases when heated, but the yield is reduced (Perdomo et al. 2013). In the cold-press method, oil has a low acid value and iodine value, with lighter color, and a high saponification value compared with Soxhlet (heat-treated)–extracted oil (Okullo et al. 2012).

18.8.5 Pretreatment of Castor Seeds

In Nigeria, as a traditional method, dehulled or undehulled castor seeds are boiled, roasted, or simply heated as raw seeds before oil extraction (Oluwole et al. 2015). When seeds were pretreated with methanol, there is a significant increase in oil yield (50% from 40%) and pour point (–21°C from –15°C), and a reduction in acid value (0.925 from 3.92 mg KOH/g) (Dasari and Goud 2014). Mgudu et al. (2012) used microwave heating before extraction with six treatments (119 W for 30, 50, and 120 s and 280 W for 30, 50, and 120 s, frequency of 2450 MHz) and control (0 W, 0 s), and reported a significant increase in oil yield (44.34% vs. 39.5% in control), and no significant change in the content of FFA (0.339% vs. 0.336% in control) and pH (7.7–8.1 vs. 7.58 in control). The records on refractive index, specific gravity, and color did not show any particular trend, and differences between treatments and control samples were not mentioned (Mgudu et al. 2012). Microwave treatment decreases the moisture content of the seeds, thereby making them more fragile and their tissues rupture easily, their cell membranes disintegrate, and porosity is increased. Also, the process is quick, requires less energy, and preserves most thermolabile compounds from oxidative deterioration (Mgudu et al. 2012). Considering these criteria, microwave preheating can be suggested as a substitute for conventional oven heating. Perdomo et al. (2013) also recommended heating the seeds before compressing in both methods to make industrial oil production economic and efficient.

Other factors, including solute-to-solvent ratio and extraction time, can be important for oil extraction (Dasari and Goud 2014). Ideally, a leaching time of 2 h at 50°C for 0.05 g of solvent per milliliter of solute has been suggested by Mbah et al. (2014). These parameters need intensive studies, as data are not available on their impact.

18.9 Uses of Castor Oil

18.9.1 Medicinal Uses

The uses described in this section are from various informal sources of literature (product brochures, company bulletins, etc.) and websites. Therefore, they should not be taken as recommendations, particularly for public health. Medical practitioners should also verify

some of these uses for future prospects because various grades of castor oil are commercially available with different acid values, moisture levels, colors, and purities. Extensive review by Atkinson (2015) enumerated recipes of castor oil for beauty and health. Therefore, only salient features are discussed below.

1. Castor oil stimulates the lymphatic system and strengthens the immune system by increasing white blood cells (WBCs) that help fight against infections, because oil increases the count of T-11 cells and production of lymphocytes in the blood and initiates more antibodies, as well as kills bacteria, fungi, viruses, and even cancer cells.
2. Traditionally, castor oil is used in the treatment of constipation and dysentery. When taken orally, oil acts as a laxative to relieve one from constipation, as it acts on the digestive track in about 4–6 h. The mode of action is that ricinoleic acid is released in the intestine and the digestive system is relaxed, facilitating bowel movement. It is also given to children orally for deworming.
3. Oil is antibacterial, antiviral, and antifungal. In an *in vitro* assay, Momoh et al. (2012) assessed essential oils of castor against 14 species of bacteria and 6 species of fungi and reported that bacteria are more susceptible than fungi. The minimum inhibitory concentration was 6.25–12.50 mg/ml for bacteria and 12.5–25 mg/ml for fungi. When compared with commercial products (erythromycin, ampiclox, rifampin, etc.), castor essential oils were found to be less effective. Castor oil is routinely used in microbial infection in the urinary bladder and vagina.
4. Being anti-inflammatory and analgesic, it is used to treat joint pains, sore muscles, and nerve inflammation. Thus, oil is the cheapest, safest, and most effective treatment option for all inflammatory, degenerative, and malignant disorders (Isah et al. 2006). Better joint pain management is done by placing a hot water bath after applying oil and by repeating this process several times for relief from arthritis. In Africa, seed kernels or hulls are boiled in milk and water. This decoction is used as a traditional remedy to relieve arthritis, low back pain, and sciatica. In the case of acne, oil helps to break up clogged skin glands and pores. It also helps to sanitize skin because it contains undecylenic acid, which kills bacteria and viruses causing acne (Salihu et al. 2014).
5. Before delivery, pregnant women are asked to drink a few tablespoons of castor oil because it induces labor by pushing uterus contraction (Kelly et al. 2013). In fact, ricinoleic acid activates prostaglandin EP3 receptors in the uterus, and thus delivery becomes easier (Tunaru et al. 2012).
6. Oil is added as an ingredient in skin care products and cosmetics (lipstick, shampoo, and soap). Application on sensitive skin is nontoxic, nonirritating, and safe because it is a cell membrane stabilizer, a valuable detergent for degreasing the matrix, and a mitochondrial cleanser (Isah et al. 2006). Application of a mixture of castor oil + baking soda dissolves corns, cysts, and moles due to the fatty acid content of the oil. It is also applied on skin against dermatitis, wound healing, acne, sunburn, keratosis, wrinkles, ringworm, and other skin infections (Salihu et al. 2014). Protection of burns and wounds from infections helps to prevent infections like dry skin warts, boils, athlete's foot, and chronic itching. Oil acts as good skin moisturizer.
7. Oil mixed with either coconut oil or almond oil initiates hair growth and thickens eyebrows and eyelashes, as it boosts blood circulation to the follicles, leading to

faster growth (Salihu et al. 2014). Castor oil is an effective cure for bald patches, and probably makes the hairs dark, because it contains omega-6 essential fatty acids, which are responsible for healthy hair (Salihu et al. 2014). In fact, this occurs in the Odisha State in India, where ladies apply castor oil to their hair almost daily to make it healthy and prevent premature shedding.

8. Castor oil is a remedy for health ailments, such as multiple sclerosis, cerebral palsy, migraine, and menstrual disorders; oral care; proper lactation; and birth control, and a medication for HIV-positive patients and those with sciatica and back pain. The American Cancer Society has suggested that the oil-based commercial product Cremophor® be used in chemotherapy against cancerous tumors, but it may cause allergy.

There are a few constraints in using castor oil. For example, skin reactions and gastrointestinal upset may occur. Oil is broken down in the small intestine into ricinoleic acid, which acts as an irritant to the intestinal lining and causes digestive discomfort due to diarrhea, cramps, irritable bowel, ulcers, diverticulitis, hemorrhoids, colitis, and prolapses. In the case of maternal labor, discomfort due to nausea is possible. Oil being thick, its application to the skin leaves a sticky feeling.

18.9.2 Industrial Uses

18.9.2.1 Biodiesel Production

Castor oil is a valuable renewable potential source of raw material for the production of biodiesel in several countries (Ogunniyi 2006; Mutlu and Meier 2010), and an array of reviews and research papers have been published on this subject. Biodiesel (also known as methyl esters of fatty acids) is nontoxic, biodegradable, and an excellent substitute for petroleum-based diesel fuel. The hydroxyl group renders ricinoleic acid as a better valuable feedstock than other oils. Since cold-flow properties are better due to the higher unsaturated fatty acid concentration, castor oil can be blended with petroleum diesel for better performance.

High solubility in methanol makes it an ideal oil for biodiesel production using esterification–neutralization–transesterification (ENT) requiring a minimum amount of catalyst and heating, and thereby reducing the cost of production (Bello and Makanju 2011). The ENT process can yield a high quantity of methyl esters with good biodiesel properties (Silitonga et al. 2016) by reducing viscosity and improving fuel quality for application in the compression ignition (Chakarbarti and Ahmad 2008). Further, transesterification can be optimized by adjustments on the type and ratio of catalysts and reagents, reaction time, catalytic system, temperature, and purification system. By using the ENT method, Armendaziz et al. (2015) recorded an oil yield of 27–431.7 kg/ha in Mexico, with ricinoleic acid methyl ester content up to 84.7%–89.2%. Generally, the best results of biodiesel production have been obtained by using (1) ethanol instead of methanol, (2) an acid catalyst instead of traditional catalysts (vegetable oils), (3) microwave heating, and (4) cosolvents.

Since castor oil has a high energy value and positive fuel properties due to fatty acid composition, its blend can be mixed with diesel at 10% (v/v) (Berman et al. 2011). Fatty acids increase oil lubricity and can therefore replace soybean, sunflower, and canola oilseeds as feedstock for biodiesel (Drown et al. 2001). It is also possible to blend it with regular diesel or biodiesel made with other lipid feedstocks (cottonseed or soybean biodiesel) up to 200 g/kg and with normal diesel at 400 g/kg (Saribiyik et al. 2010). It is a common motor lubricant for internal combustion engines due to its high boiling and low melting

points, and resistance to heat compared with petroleum-based oils (Ogunniyi 2006; Mutlu and Meier 2010).

Castor oil is being increasingly used in the pharmaceutical and chemical industries to manufacture high-value products, but it becomes uneconomical to use it for biodiesel with the high cost of feedstock. Castor oil biodiesel may pose difficulties in internal combustion engines because of its high density, viscosity, and hydroscopic properties. These constraints, however, are minor, considering its easy availability and potential for biodiesel production.

18.9.2.2 Other Industrial Uses

Recent consumer awareness toward green consumerism has made food industries search for preservatives for safe, healthy, and nutritious food. Essential oils offer an appropriate solution to this (Prakash and Kiran 2016). As such, castor oil is used in food industries as an additive and flavoring agent because glycerol, popularly known as glycerin, is a sugar alcohol that has a sweet taste and low toxicity. Dietary intake per the International Castor Oil Association is as high as 10% for 90 days without any ill effects. The Joint FAO/WHO Committee on Food Additives has established an acceptable daily oil intake of up to 0.7 mg/kg of body weight, for example, 1 tablespoon for adults and 1 teaspoonful for children. Oil in a processed form, known as polyglycerol polyricinoleate, is used in chocolate bar manufacturing as a less expensive substitute for cocoa butter and as a mold inhibitor to prevent rotting in rice, wheat, and pulses (Wilson et al. 1998). In the future, there is a great scope for essential oils in the marketing chain by improving current food products by using nanoencapsulation, edible coatings, and controlled-release systems.

Thomas et al. (2015) discussed the industrial perspectives of castor oil. Oil serves as a raw material in paint and nylon industries (Thomas et al. 2015). The Turkey red oil (sulfonated castor oil) is used to manufacture industrial lubricants, hydraulic and brake fluids, plastics, and detergents, and in the treatment of leather and other industrial products, such as nylon-6, nylon-10 from sebacic acid, and nylon-11 from 11-amino-undecanoic acid (Isah 2006). The essential oils of nine plants were assessed against two fungi, *Aspergillus niger* Tiegh. and *Geotrichum candidum* Link, to protect wooden structures. Among them, castor oil showed the lowest effectiveness at all doses (5, 10, 20, 30, and 50 ppm). However, a paint containing oil can be an eco-friendly approach in buildings and indoor environments (Verma et al. 2011).

Unsaturated polyester resin (UPR) can be fabricated from oil through blending pentaerythritol glyceride maleates with petroleum-based UPR (Liu et al. 2014). This resin is suitable for a liquid molding process with less shrinking and better mechanical and thermal properties (Liu et al. 2014). Glycerol in castor oil is converted to acrolein and epichlorohydrin and used as a raw material for epoxy resins and for the manufacturing of polyols for flexible foams and, to a lesser extent, rigid polyurethane foams (Thomas et al. 2015). Glycerol is also used to produce nitroglycerin (an essential heart medication) and ingredients of dynamite (smokeless gun powder) and other explosives, fuel components (hydrogen gas production and conversion to ethanol), and chemical products (citric acid, ethylene, and propylene glycol) (Thomas et al. 2015). Detergent manufactured from castor oil is biodegradable and better than synthetic detergents (Isah 2006).

Apart from the above-mentioned major uses, castor oil is an ingredient in the manufacture of aviation fuels, transparent typewriter and printing inks, soaps, textile dyes, coatings, polishes, varnishes, lacquers, grease, hydraulic fluids, linoleum, and coatings of fabrics due to its semidrying property (Ogunniyi 2006; Perdomo et al. 2013; Thomas et

al. 2015). Oil serves as bio-based renewable monomers and polymers that are used in the manufacturing of polyurethanes, polyesters, and polyamides (Mutlu et al. 2010).

18.10 Castor Oil as Pesticide

Castor oil proved effective against insect pests and diseases of agricultural crops and stored commodities, including food grains. Table 18.8 shows various modes of action of castor oil. Insects and disease pathogens affecting human health are also discussed in this section, with an objective of facilitating an effective control program using castor oil as one of the components.

18.10.1 Insect Pests and Diseases of Field Crops

In greenhouse trials, a castor oil–based detergent at 1.5 ml/L in aqueous solution or 10% mixture in water was added to pesticides for spraying a strawberry crop in Brazil. The application resulted in a better control of ants (*Atta* spp.), leaf-feeding beetles (*Epilachna* spp.), red spider mite (*Tetranychus urticae* Koch), anthracnose (*Colletorichum gloeosporioides* [Penz.] Penz. & [Sacc.]), gray mold rot (*Botrytis cinera* Pers.), and bacterial blight or leaf spot (*Xanthomonas fragariae* Kennedy & King) (Galhiane et al. 2012). The residue of pesticides (deltamethrin, folpet, tebuconazle, abamectin, and mancozeb) was at a lower level than when pesticides were used without oil. In a 3-year survey in India, it was found that spraying of a mixture of 3% castor oil + butter milk + extract of fenugreek, betel vine, and onion is practiced by tribal communities to control insect pests on peanut and pulses (Mohapatra et al. 2009). These examples show that castor oil can be a potential synergist for organic and synthetic pesticides. The diamondback moth, *Plutella xylostella* L., was successfully controlled under both laboratory and semifield conditions (Kodjo et al. 2011). In the laboratory, complete mortality of third-instar larvae was achieved with 10% oil emulsion (topical application and ingestion methods) compared with 2%–5% mortality in control and 82%–88% mortality with 5% chlorpyriphos (Dursban®) dusting. Lowest adult emergence (42.3%) and the highest abnormal adults (48%–79%) were also recorded. In field caged cabbage plants, larval mortality (57.7%), adults without deformities (23.7%), and longevity (8–9 days) were reported with 5% castor oil. The corresponding data on untreated plants were 10% mortality, 98% adults without deformity, and longevity of 12–13 days (Kodjo et al. 2011). In yam (*Dioscorea* sp.), infection on tubers caused by two fungi, *Aspergillus flavus* Tiegh and *Fusarium verticillioides* (Sacc.) is common. In an *in vitro* test, crude oil lowered the growth and development of fungal mycelium and showed potential in disease control (Makun et al. 2011).

In a green gram (*Vigna radiata* [L.]) pot culture experiment, the damage of the root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, was studied by Wani and Bhat (2012). They found that the soil application of urea coated with castor oil at 0.06 g/pot significantly reduced the root-knot index (1.3 vs. 4.6 in control, rated on a 0–5 scale, 5 ≥ 100 galls/root) and improved the root nodule index (3.3 vs. 1.1 in control, rated on a 1–5 scale, 5 = 100 nodules/root). However, urea coated with neem-based Nimin® gave better results. Similarly, in laboratory and greenhouse experiments on cucumber plants, castor seed oil at 1000 ppm inhibited egg hatching of *M. incognita*, 72 h after treatment, by 71.3% and reduced egg hatching by 16%, thus resulting in low gall density (Katooli et al. 2010).

TABLE 18.8

Examples of Field and Storage Pests and Disease Pathogens Controlled with Castor Oil

Crop/Commodity	Pest/Pathogen Species (Family)	Mode of Action	References
Strawberry (F)	*Epilachna* sp. (Coccinellidae)	SY	Galhiane et al. 2012
	Tetranychus urticae (Tetranychidae)	SY	Galhiane et al. 2012
	Colletotrichum gloesporioides (Glomerellaceae)	SY	Galhiane et al. 2012
	Botrytis cinerea (Sclerotiniaceae)	SY	Galhiane et al. 2012
	Xanthomonas fragariae (Xanthomonadaceae)	SY	Galhiane et al. 2012
Cabbage (GH)	*Plutella xylostella* (Plutellidae)	IGR, IN	Kodjo et al. 2011
Bean (S)	*Zabrotes subfasciatus* (Chrysomelidae)	IN	Mushobozy et al. 2009
Cowpea (S)	*Callosobruchus chinensis* (Bruchidae)	OD, OV, IN	Bhargava and Meena 2002; Neog and Singh 2012
Cowpea (S)	*Callosobruchus maculatus* (Bruchidae)	IN, IGR, IN, OD, OV, RE	Haghtalab et al. 2009; Shinde et al. 2011; Fouad 2013a; Yahaya et al. 2013
Cowpea (S)	*Acanthoscelides obtectus* (Bruchidae)	IGR, IN, OD, OV	Nana et al. 2014
Chickpea (S)	*Callosobruchus maculatus* (Bruchidae)	IN	Paceco et al. 1995
Maize (S)	*Sitiphilus zeamais* (Curculionidae)	IN	Wale and Assegie 2015
Coffee (S)	*Hypothenemus hampei* (Curculionidae)	IN	Mohapatra et al. 2009; Celestino et al. 2016
Green gram (GH)	*Meloidogyne incognita* (Heteroderidae)	NE	Wani and Bhat 2012
Green gram (S)	*Callosobruchus hinensis* (Bruchidae)	IN	Singh and Yadav 2003
Green gram (S)	*Callosobruchus maculatus* (Bruchidae)	IGR, OD, RE	Ratnasekara and Rajapakse 2009
Pigeon pea (S)	*Callosobruchus chinensis* (Bruchidae)	IN	Kadve et al. 2016
Wheat (S)	*Trogoderma granarium* (Dermestidae)	IGR, IN	Jakhar and Jat 2010
	Sitophilus oryzae (Curculionidae)	IN	Meghwal et al. 2012
	Rhyzopertha dominica (Bostrichidae)	IN	Patel and Vekaria 2013

Note: F, field; GH, greenhouse; IGR, insect growth regulator; IN, insecticidal/toxic; NE, nematicidal/toxic; OD, oviposition deterrent; OV, ovicidal; RE, repellent; S, storage; SY, synergist.

18.10.2 Insect Pests of Stored Food Grains

In the laboratory, a pulse beetle or adzuki bean beetle, *Callosobruchus chinensis* (L.), was controlled with seed treatment of castor oil at 1 ml/100 g of seeds of cowpea with 80.7% mortality in adults 3 days after treatment (DAT). It inhibited oviposition (26.5 eggs/female vs. 79.4 eggs in control), reduced egg viability up to 61.7%, and reduced F1 progeny by 85% (Bhargava and Meena 2002). Recently, Kadve et al. (2016) reported the effectiveness of pigeon pea seed treatment with castor oil at 5 ml/kg, in terms of fecundity (66 eggs/100 seeds vs. 122 eggs in untreated seeds), adult emergence (26.6% vs. 88.3% in control), and resulting seed damage (26.3% vs. 85% in control) and seed weight loss (9.3% vs. 20.7% in control). The best treatment, however, was seed treatment with deltamethrin 2.8EC at 0.04 ml/kg, with significantly reduced pest fecundity, adult emergence, seed damage, and weight loss, and better seed germination (90% compared with 81% with castor oil and 50% in untreated seeds) (Kadve et al. 2016). In a trial with the powder (5%, w/w) of leaves or the seed coat of 10 plants, 8 vegetable oils (1%, w/w), and malathion dust (1%, w/w) tested for 2 years against pulse beetle (Neog and Singh 2012), castor oil performed well with 3.33%–4.33% infestation against 56.7%–61.3% in control. In another test, castor oil at seven doses (4, 5, 6, 7, 8, 9, and 10 ml/kg of seeds) with an exposure of 24–120 h showed that insect mortality was dependent on dose and exposure period, with a maximum mortality of 86.7% at 9 ml/kg of seeds with an LC_{95} of 10.9 ml/kg for 72 h in the cowpea seed beetle, *Callosobruchus maculatus* (F.), in stored cowpea (Haghtalab et al. 2009), and a mortality of 99.1% at 9 ml/kg with an LC_{95} value of 2.95 ml/kg for 120 h in the common bean weevil, *Acanthoscelides obtectus* (Say), in bean (*Phaseolus vulgaris* L.) (Nana et al. 2014).

A mixture of castor oil + neem oil (both 2%) in a 1:1 proportion used for treating cowpea seeds at 2 ml/50 g of seeds significantly reduced fecundity of *C. maculatus* at 14 days after treatment (4.7 eggs/50 g of seeds vs. 41.7 eggs in control). When castor oil was used alone, the fecundity was 7.63 eggs/50 g of seeds versus 44.8 eggs in control (Yahaya et al. 2013). Castor oil applied at 5 ml/kg seed inhibited egg laying (38 eggs/200 g of seeds vs. 161 eggs in control); reduced egg hatching (60% vs. 100% in control), adult longevity (1.1 days vs. 9.7 days in control), the infestation rate after 3 months of storage (9.65% vs. 51.5% in control), and adult emergence (4.5 adults/100 g of seeds vs. 131 adults in control); and prolonged the development period (33 days vs. 25 days in control) (Shinde et al. 2011). At a higher dose at 10 ml/kg of seeds, castor oil gave protection to stored green gram up to 280 days, with significant mortality in *C. chinensis* grubs (Singh and Yadav 2003).

Castor oil applied at 1 ml/100 g of seed gave 100% protection for 150 days in chickpea from *C. maculatus*, and for 90 days from the bean beetle, *Callosobruchus phaseoli* (Gyllenhal), in bean (Paceco et al. 1995). A mixture of essential oils + acetone on filter paper was tested in the laboratory against *C. maculatus* at 0.01%, 0.1%, and 1%. In a free choice at 1%, castor oil showed only 1.5% repellency compared with cinnamon oil (47.5% repellency) after 4 h of treatment (Fouad 2013a). In another experiment, essential oils of camphor, castor, cinnamon, mustard, and clove oil at 0.5%, 1%, 2%, and 4% against the faba bean beetle, *Bruchidius incarnatus* (Boheman), were tested (Fouad 2013b). From toxicity and repellent activities, the superiority of cinnamon (*Cinnamomum zeylanicum*) oil was confirmed, whereas castor oil was not effective as either a repellent or an insecticidal, even at the highest concentration of 4% (e.g., repellency of 12.1% with castor oil vs. 54.1% with cinnamon oil recorded 1 h after exposure). In a test on oil vapors at 200 µl/20 seeds of green gram, Ratnasekara and Rajapakse (2009) observed significant reduction in the rate of oviposition and adult emergence in *C. maculatus* due to effective repellent action of castor oil, but it was inferior to that of mustard oil, *Solanum indicum* L. or *Calophyllum inophyllum* L. In cowpea stored

in a silo in Africa, damage by two bruchids (*C. maculatus* and *Bruchidius atrolineatus* [Pic.]) was significantly reduced by treating seeds with castor oil at 6 ml/kg (Yakubu et al. 2012).

When stored seeds of wheat were treated at 1 ml/100 g of seeds, the duration of larval and pupal development of the khapra beetle, *Trogoderma granarium* Everts, was significantly prolonged (32.6 days vs. 25.1 days in untreated seeds) (Jakhar and Jat 2010). This treatment also reduced adult emergence to 31.3% from 64% in the control and recorded threefold less damage in treated grains (13% vs. 39% in control) (Jakhar and Jat 2010). The rice weevil, *Sitophilus oryzae* (L.), attacking stored wheat was best controlled by mustard oil (75% mortality and 4.53% grain damage), followed by castor oil (61.7% mortality and 7.6% grain damage) (Meghwal et al. 2012). Similarly, only 88% of adults emerged in castor oil–treated grains. In Ethiopia, mortality of the maize weevil, *Sitophilus zeamais* (Mots.), with 2 ml of oil/kg of stored maize was 53% 1 h after treatment, but it increased to >85% when the dose was increased; the corresponding LD_{50} was 2.04 ml (Wale and Assegie 2015). In Brazil, in a control trial against the coffee berry borer, *Hypothenemus hampei* (Ferrai), castor oil applied at 3% (v/v) resulted in 53.7% mortality with an LC_{50} of 3.49% against 40.8% mortality and an LC_{50} of 6.71% in water-sprayed berries (Celestino et al. 2016). Mohapatra et al. (2009) reported from a 3-year survey in India an effective control for the coffee borer with a seed treatment of a mixture of 3% castor oil + 3% peanut oil at 10 ml/kg of seeds.

Castor oil at a concentration of 10 mg/ml proved effective as a strong repellent (58.66%) against the red flour beetle, *Tribolium castaneum* (Herbst), with an LD_{50} value of 5.52 mg/cm for 24 h, with a dose of 2.04 mg/cm^2 resulting in significant reduction in egg hatching, survival rate of larvae, and adult emergence (Islam et al. 2014). On the contrary, Jenan (2014) reported 100% mortality in first- through third-instar larvae of the confused flour beetle, *Tribolium confusum* (Val), and khapra beetle due to fumigant action of 10% castor oil in acetone, against only 40% mortality in acetone (control). The seed protectant capacity of essential oil of castor due to contact toxicity (LD_{50} of 615.28 μg/cm^2) and fumigant toxicity (LD_{50} of 5.52 and 4.05 mg/cm 24 and 48 h after treatment) was demonstrated against *T. castaneum* by Islam et al. (2014). Khalequzzaman and Choudhury (2003) evaluated four oils, each mixed with pirimophos–methyl in a 1:10 proportion, and reported the maximum toxic effect against four strains of *T. castaneum*, with an LD_{50} of 0.264–0.355 μg/cm^2 for pesticide and 9.48–42.97 μg/cm^2 for castor oil. The maximum synergism evaluated by a cotoxicity coefficient value was for neem oil (4908.53), followed by sesame oil (434.11), castor oil (295.24), and soybean oil (232.93). This test demonstrated the use of castor oil as a potential synergist.

Wheat seeds were treated with crude castor oil against the lesser grain borer, *Rhyzopertha dominica* (Fb.). There was significantly lower grain damage (9.9% vs. 13% in control) and less seed weight loss (5.6% vs. 11.4% in control), but deltamethrin 2.8EC (0.01 ml/kg) proved to be the most effective treatment (Patel and Vekaria 2013). Infestation of the Mexican bean beetle, *Zabrotes subfasciatus* (Boh.) was controlled by treating bean seeds with castor oil at 5 ml/kg. This treatment was as effective as the oil of sesamum, oil palm, cotton, or maize, but it was inferior to malathion dust (2%) applied to seeds at 0.5 g/kg (Mushobozy et al. 2009). From the examples cited, it can be concluded that crude castor oil applied at various doses either for spraying field crops or treating stored food grains could effectively control insects, nematodes, and plant pathogens.

18.10.3 Insects Affecting Human Health

Castor oil is an effective repellent against mosquitoes. It is applied on the body or embodied in lotion, cream, paste, and other preparations, either to facilitate application or for

a more lasting effect (Patel et al. 2012). The commercial product Bite Blocker Xtreme®, containing 8% castor oil + 3% soybean oil + 6% geranium oil, has given protection up to 163 min against the flood water mosquito, *Psorophora columbiae* (Dyar & Knob.), in the United States (Qualls et al. 2011). By using a misting system, Cilek et al. (2011) compared essential oils of castor with commercial repellents against two caged mosquito species: dengue/Asian tiger mosquito, *Aedes albopunctus* (Skuse), and home mosquito, *Culex quinquefasciatus* (Say). Castor oil (3%) applied at a dose of 4 ml/L resulted in lower mortality, but repellency was equal compared with two commercial products, Riptide® containing 5% pyrethrin (9 ml/L) and Ecoexempt® containing 18% rosemary oil (9 ml/L). Castor oil is an effective repellent to household insects, including cockroaches, which spread human diseases (Patel et al. 2012). In a laboratory trial, ricinoleic acid esters from castor oil showed cytoplasmic changes that inhibited the development of oocytes and proved to be an effective acaricide against the brown dog tick, *Rhipicephalus sanguineus* (Latreille), which is a recognized vector of many pathogens (Arnosti et al. 2010).

18.11 Advantages and Limitations of Oil as a Pesticide

Castor cultivation is easy and profitable, and therefore seed availability in large quantities around the year is possible by planting on large areas. Phytotoxicity due to vegetable and organic oils on agricultural crops has not been reported (Galhiane et al. 2012; Nagar et al. 2012). In crop protection, plant-derived products are used due to their comparatively low cost of preparation, low toxicity to natural enemies of crop pests, safety to humans, biodegradability, and having no record of development of resistance in pests (Gahukar 2014). Moreover, oil affects physiological, nutritional, and behavioral processes, resulting in insect mortality, and shows diverse effects, such as antifeedant, oviposition-deterrent, ovicide, growth regulation and fecundity reduction, and fungal mycelium effects, as well as inhibition of the hatching of insect eggs and root penetration of nematodes. The potential of oil against insect vectors of human diseases plays a significant role in public health. In some instances, the addition of oil to chemicals or other products increased pest mortality and not only showed promising results in crop protection through synergism, but also reduced treatment cost (Gahukar 2014).

There are some limitations that may hinder use of oil. In crop and seed protection, the quality of the crude oil reflects its performance in pest control. For example, while listing pests of stored castor seeds in Africa, Salihu et al. (2014) mentioned the infestation of three insects (*T. castaneum*, the cigarette beetle; *Lasioderma serricorne* [Fb.], and the tropical warehouse moth, *Ephestia cautella* [Walker]) that resulted in deterioration of the quality of seeds, and thereby the quality of oil, making it unsuitable as a pesticide. Similarly, reports from India (Lalithakumari et al. 1971) and Africa (Negedu et al. 2014) showed that oil quality was considerably deteriorated by fungi, *Aspergillus tamarii* (Kita) and *Aspergillus* spp. This fact was evidenced from a significant increase in the content of the moisture, crude protein, ash, crude fiber, and peroxide value, and a significant reduction in the content of the total fat and soluble sugar (Negedu et al. (2014). Thus, stored seeds attacked by insects and disease pathogens become unsuitable for oil extraction.

Seed germination was lowered by 20%–30% when castor oil was used to treat the seed of pulses in India (Raghuwani and Kapadia 2003; Sanappa and Acharya 2014) and maize seeds in Ethiopia (Wale and Assegie 2015). Castor oil treatment at 5 ml/kg to maize seeds against

disease pathogens resulted in seed germination up to 64% against 80% with captan at 3 g/kg, but seed vigor was much better in seedlings from oil-treated seeds (Wani et al. 2014).

In the tropics, residual persistence of castor oil on crop plants is affected due to the high temperature in the summer and runoff from plants due to heavy rains during the rainy season. Further, slow toxic action and less effectiveness compared with chemicals make farmers reluctant to use castor oil in pest control. In countries where poor farmers cannot buy costly synthetic pesticides, castor oil–based "ready-to-use" products are not available in the local market. Also, infrastructure for storing seeds, technical know-how for extraction, and quality testing are lacking at the village level, as reported by Morse et al. (2002) for Nigeria. Also, nonstandardization of extraction methods and determination of the physical, chemical, and engineering properties of the oil, fatty acid fractions, and derived chemical feedstocks make biodiesel incompetent in commercial chains.

18.12 Conclusions

For extracting castor oil of reasonably high quality, heathy seeds are needed. Therefore, storage conditions should be kept ideal for long shelf life. Considering yield and quality parameters for ultimate utilization of castor oil in industries, chemical extraction proved efficient compared with wet or mechanical extraction. Since castor oil is readily available through large-scale cultivation of castor crop that farmers can cultivate without much technical help and money, its utilization as an insecticide needs to be promoted as seed treatment to reduce pest infestation in stored commodities. In the future, intensive studies may show promising results against pests affecting human health. Of course, there are some limitations that need the attention of researchers and drug manufacturers.

Biodiesel production shows a significant perspective, particularly to reduce greenhouse gas (GHG) emission (Severino et al. 2012). Biodiesel engines have a lower impact on environment than those operating on petroleum fuel (Chakrabarti and Ahmad 2008). These aspects are important to avoid GHG emissions in the environment. Castor oil replacing the feedstock of seeds of cotton, soybean, sunflower, and canola oil should be encouraged, as their consumption as human food and animal feed has increased in recent years.

In food industries, new preservatives based on essential oils should be tested for their toxicology, environmental effect, and product chemistry to ensure their quality and safety to human health. From this perspective, collaboration between the scientific community, food industries, and regulatory authorities is needed at local and national levels.

References

Abdelaziz, A.I.M., Elamin, I.H.M., Gasmelseed, G.A., Abdalla, B.K. 2014. Extraction, refining and characterization of Sudanese castor seed oil. *J. Chem. Eng.* 2(1): 1–4. http://researchpub.org/journal/jce/number/vol2-no1/vol2-no1-1/pdf.

Abitogun, A., Alademeyin, O., Oloye, D. 2008. Extraction and characterization of castor seed oil. *Internet J. Nutr. Wellness* 8(2).

Akartha, O., Anusiem, A.C.I. 1996. A bioresource solvent for extraction of castor oil. *Ind. Crops Prod.* 5: 273–77.

Akpan, U.G., Jimoh, A., Mohammed, A.D. 2006. Extraction, characterization and modification of castor seed soil. *Leonardo J. Sci.* 8: 43–52.

Alizeralu, A.F.N., Shirzad, H., Harzati, S. 2011. The effect of climatic factors on the production and quality of castor oil. *Nature Sci.* 9(4): 15–19.

Anjani, K. 2012. Castor genetic resources: A primary genepool for exploitation. *Ind. Crops Prod.* 35: 1–14.

Armendaziz, J., Lapuerta, M., Zavala, F., Garcia-Zambrano, E., Ojeda, M.C. 2015. Evaluation of eleven genotypes of castor oil plant (*Ricinus communis* L.) for the production of biodiesel. *Ind. Crops Prod.* 77: 484–90.

Arnosti, A., Brienza, P.D., Furquim, K., Mathias, M.I.C. 2010. Effects of ricinoleic acid esters from castor oil (*Ricinus communis*) on the vitellogenesis of *Rhipcephalus sanguineus* (Latreille, 1806) (Acari: Ixodidae) tick. *Exp. Parasitol.* 127(2): 575–80.

Atkinson, A. 2015. *Essential Oils for Beauty, Wellness and the Home: 100 Natural Non-Toxic Recipes for the Beginner and Beyond*. New York: Skyhorse Publishing.

Bello, E.I., Makanju, A. 2011. Production, characterization and evaluation of castor oil biodiesel as alternative fuel for diesel engines. *J. Emerg. Trends Eng. Appl. Sci.* 2(3): 525–30.

Berman, P., Nizri, S., Wiesman, Z. 2011. Castor oil biodiesel and its blends as alternative fuel. *Biomass Bioenergy* 35(7): 2861–66.

Bhargava, M.C., Meena, B.L. 2002. Efficacy of some vegetable oils against pulse beetle, *Callosobruchus chinensis* (Linn.) on cowpea, *Vigna unguiculata* (L.). *Indian J. Plant Prot.* 30(1): 46–50.

Canvin, D.T. 1965. The effect of temperature on the oil content and fatty acid composition of the oils from several oil seed crops. *Can. J. Bot.* 43(1): 63–69.

Celestino, F.N., Pratissoli, D., Machado, L.C., Santos, H.J.G., Jr., Queiroz, V.T., Mordgan, L. 2016. Control of coffee berry borer, *Hypothenemus hampei* (Ferrai) (Coleoptera: Curculionidae: Scolytinae) with botanical insecticides and mineral oils. *Acta Sci. Agron.* 38(1): 1–8.

Chakrabarti, M.H., Ahmad, R. 2008. Trans-esterification studies on castor oil as a first step towards its use in biodiesel production. *Pak. J. Bot.* 40(3): 1153–57.

Cilek, J.E., Hallmon, C.F., Johnson, R. 2011. Efficacy of several commercially formulated essential oils against caged female *Aedes albopunctus* and *Culex quinquefasciatus* when operationally applied via an automatic-timed insecticide application system. *J. Am. Mosquito Contr. Assoc.* 27(3): 252–55.

Compton, D.L., Laszio, J.A., Evans, K.O. 2015. Phenylpropanoid esters of lesquerella and castor oil. *Ind. Crops Prod.* 63: 9–16.

Conceicao, M.M., Candeia, R.A., Silva, F.C., Bezerra, A.F., Fernandes, V.J., Jr., Souza, A.G. 2007. Thermoanalytical characterization of castor oil biodiesel. *Renew. Sustain. Energy Rev.* 11: 964–75.

Cvengros, J., Paligova, J., Cvengrosova, Z. 2006. Properties of esters base on castor oil. *Eur. J. Lipid Sci. Technol.* 108(8): 629–35.

Dasari, S.R., Goud, V.V. 2014. Effect of pretreatment on solvents extraction and physicochemical properties of castor seed oil. *J. Renew. Sustain. Energy* 6: 063108.

Drown, D.C., Harper, K., Frame, E. 2001. Screening vegetable oil alcohol esters as fuel lubricity enhancers. *J. Am. Oil Chem. Soc.* 78(6): 579–84.

Fouad, H.A. 2013a. Effect of five essential oils as repellents against the cowpea weevil, *Callosobruchus maculatus* (F.). *Bull. Environ. Pharm. Life Sci.* 2(5): 23–27.

Fouad, H.A. 2013b. Bioactivity of essential oils of medicinal plants against *Bruchidius incarnatus* (Boheman 1833). *Res. J. Agric. Environ. Manage.* 2(6): 136–41.

Gahukar, R.T. 2014. Potential and utilization of plant products in pest control. In *Insect Pest Management: Current Concepts and Ecological Perspectives*, ed. D.P. Abrol, 125–139. New York: Elsevier.

Galhiane, M.S., Rissato, S.R., Santos, L.S. et al. 2012. Evaluation of the performance of a castor oil-based formulation in limiting pesticide residues in strawberry crops. *Quimica Nova (Sao Paulo)* 35(2).

Haghtalab, N., Shayesteh, N., Aramideh, S. 2009. Insecticidal efficacy of castor and hazelnut oils in stored cowpea against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *J. Biol. Sci.* 9(2): 178–79.

Isah, A.G. 2006. Production of detergent from castor oil. *Leonardo Electronic J. Pract. Technol.* 9: 153–60.

Islam, M.R., Song, C.H., Jeong, Y.T. et al. 2014. Bioprotectant capacities of essential oil from *Ricinus communis* (L.) against stored product red flour beetle, *Triboium castanium* (Herbst). *J. Parasitol. Photon* 104: 150–56.

Jakhar, B., Jat, S.L. 2010. Efficacy of plant oils as grain protectants against beetle, *Trogoderma granarium* Everts in wheat. *Indian J. Entomol.* 72(3): 205–8.

Jenan, U. 2014. Fumigant toxicity of *Ricinus communis* L. oil on adults and larvae of some stored product insects. *J. Nat. Sci. Res.* 4(4): 26–29.

Kadve, P.S., Gawande, R.W., Deotale, R., Rathod, K.B., Lavhe, N.V. 2016. Evaluation of different organic products against pigeon pea pulse beetle, *Callosobruchus chinensis* L. *Pestology* 40(5): 36–41.

Kallamadi, P.R., Ranga Rao Nadigotla, V.P.R., Mulpuri, S. 2015. Molecular diversity in castor (*Ricinus communis* L.). *Ind. Crops Prod.* 66: 271–81.

Katooli, N., Moghadam, E.M., Tahen, A., Nasrollahnejad, S. 2010. Management of root-knot nematode (*Meloidogyne incognita*) on cucumber with the extract and oil of nematicidal plants. *Int. J. Agric. Res.* 5: 582–86.

Kelly, A.J., Kavanagh, J., Thomas, J. 2013. Castor oil, bath and/or enema for cervical priming and induction of labour. *Cochrane Database Syst. Rev.* 7: CD003099.

Khalequzzaman, M., Choudhury, F.D. 2003. Evaluation of mixtures of plant oils as synergists for pirimophos-methyl in mixed formulation against *Tribolium castaneum* (Herbst). *J. Biol. Sci.* 3(3): 347–59.

Kodjo, T.A., Gbenonchi, M., Sadate, A., Homi, A., Dieudonne, G.Y.M., Komla, S. 2011. Bio-insecticidal effects of plant extracts and oil emulsions of *Ricinus communis* L. (Malpighiales: Euphorbiaceae) on the diamondback, *Plutella xylostella* L. (Lepidoptera: Pluttellidae) under laboratory and semi-field conditions. *J. Appl. Biosci.* 43: 2899–914.

Lalithakumari, D., Vidhyasekharan, P., Govindaswamy, C.V., Doraiswami, S. 1971. Reduction in oil content of castor seed due to storage fungi. *Curr. Sci.* 40: 273.

Liu, C., Li, J., Lei, W., Zhou, Y. 2014. Development of biobased unsaturated polyester resin containing highly fractionalized castor oil. *Ind. Crops Prod.* 52: 329–37.

Makun, H.A., Anjorin, S.T., Adeniran, L.A. et al. 2011. Antifungal activities of *Jatropha curcas* and *Ricinus communis* seeds on *Fusarium verticillioides* and *Aspergillus flavus* in yam. *ARPN J. Agric. Biol. Sci.* 6(6): 22–27.

Mbah, G.O., Amulu, N.F., Onyiah, M.I. 2014. Effects of process parameters on the yield of oil from castor seed. *Am. J. Eng. Res.* 3(5): 179–86.

Meghwal, H.P., Bajpai, N.K., Chaudhary, H.R. 2012. Efficacy of vegetable oils as grain protectant against *Sitophilus oryzae* (L.) in stored maize. *Indian J. Entomol.* 74(1): 9–12.

Meneghetti, S.M.P., Meneghetti, M.R., Wolf, C.R. et al. 2006. Biodiesel from castor oil: A comparison of ethynolysis versus methynolysis. *Energy Fuels* 20(5): 2262–65.

Mgudu, L., Muzenda, E., Kabula, J., Belaid, M. 2012. Microwave-assisted extraction of castor oil. Presented at International Conference on Nanotechnology and Chemical Engineering, Bangkok, December, 21–22.

Mohammed, M.H., Mursey, H.M. 2015. Improving quantity and quality of castor bean oil for biodiesel growing under severe conditions in Egypt. *Energy Procedia* 68: 117–21.

Mohapatra, P., Ponnurasan, N., Narayanaswamy, P. 2009. Tribal pest control practices of Tamil Nadu for sustainable agriculture. *Indian J. Trad. Know.* 8(2): 218–24.

Momoh, A.O., Oladunmoye, M.K., Adebolu, T.T. 2012. Evaluation of the antimicrobial and phytochemical properties of oil from castor seeds (*Ricinus communis* Linn.). *Bull. Environ. Pharm. Life Sci.* 1(10): 21–27.

Morse, S., Ward, A., McNamara, N., Denholm, I. 2002. Exploring the factors that influence the uptake of botanical insecticides by farmers: A case study of tobacco based products in Nigeria. *Exp. Agric.* 38: 469–79.

Mushobozy, D., Nganilevanu, G., Ruheza, S., Swella G. 2009. Plant oils as common bean (*Phaseolus vulgaris*) seed protectants against infestation by the Mexican bean weevil, *Zabrotes subfasciatus* (Boh.). *J. Plant Prot. Res.* 49(1): 35–40.

Mutlu, H., Meier, M.A.R. 2010. Castor oil as a renewable resource for the chemical industry. *Eur. J. Lipid Sci. Technol.* 112(1): 10–30.

Nagar, A., Singh, S.P., Singh, Y.P., Singh, R., Meena, H., Nagar, R. 2012. Bioefficacy of vegetable and organic oils, cakes and plant extracts against mustard aphid, *Lipaphis erysimi* (Kalt.). *Indian J. Entomol.* 74: 114–19.

Nana, P., Nchu, F., Bikomo, R.M., Kutima, H.L. 2014. Efficacy of vegetable oils against dry bean beetles. *Afr. Crop Sci. J.* 22(3): 175–80.

Nangbes, J.G., Nvak, J.B., Buba, W.M., Zukdimma, A.N. 2013. Extraction and characterization of castor (*Ricinus communis*) seed oil. *Int. J. Eng. Sci.* 2(9): 105–9.

Negedu, A., Joseph, A.B., Umoh, U.J., Atawodi, S.E., Rai, M. 2014. Biodeterioration of stored castor (*Ricinus communis*) seeds by *Aspergillus tamarii*. *Nusantara Biosci.* 6(2): 126–31.

Neog, P., Singh, H.K. 2012. Efficacy of plant powders and vegetable oils against *Callosobruchus chinensis* (L.) on stored green gram. *Indian J. Entomol.* 74(3): 267–73.

Ogunniyi, D.S. 2006. Castor oil: A vital industrial raw material. *Bioresour. Technol.* 97(9): 1086–91.

Okullo, A., Temu, A.K., Oguwok, P., Ntalikwa, J.W. 2012. Physico-chemical properties of biodiesel from jatropha and castor oils. *Int. J. Renew. Energy Res.* 2: 47–56.

Olaniyan, A.M. 2010. Effect of extraction conditions on the yield and quality of oil from castor bean. *J. Cereals Oilseeds* 1(2): 24–33.

Oluwole, F.A., Abdulrahim, D.T., Aviara, N.A., Nana, S. 2012. Traditional method of extracting castor oil. *Continental J. Eng. Sci.* 7(2): 6–10.

Oluwole, F.A., Aviara, N.A., Umar, B., Mohammed, A.B. 2015. Influence of variety and pre-treatment on oil properties by mechanically expressed castor oil. *Global Adv. Res. J. Eng. Technol. Innov.* 4(1): 1–9.

Omari, A., Mgani, Q.A., Mubofu, E.B. 2015. Fatty acid profile and physico-chemical parameters of castor oils in Tanzania. *Green Sustain. Chem.* 5(4): 154–63.

Paceco, I.A., de Castro, M.F.P.P.M., de Paula, D.C., Lourencao, A.L., Bolonhezi, S., Barbieri, M.K. 1995. Efficacy of soybean and castor oils in the control of *Callosobruchus maculatus* (F.) and *Callosobruchus phaseoli* (Gyllenhal) in stored chick peas. *J. Biol. Sci.* 9(2): 175–79.

Patel, A.V., Vekaria, M.V. 2013. Management of lesser grain borer, *Rhyzopertha dominica* (F.) on wheat. *Indian J. Entomol.* 75(4): 347–48.

Patel, E.K., Gupta, A., Oswal, R.J. 2012. A review on mosquito repellent methods. *Int. J. Pharm. Chem. Biol. Sci.* 2(3): 310–17.

Pecina-Quintero, V., Anaya-Lopez, J.L., Nunez-Colin, C.A. et al. 2013. Assessing the genetic diversity of castor bean from Chiapas, Mexico using SSR and AFLP markers. *Ind. Crops Prod.* 41: 134–43.

Perdomo, F.A., Acosta-Osorio, A.A., Herrera, G. et al. 2013. Physicochemical characterization of seven Mexican *Ricinus communis* L. seeds & oil contents. *Biomass Bioenergy* 48: 17–24.

Prakash, B., Kiran, S. 2016. Essential oils: A traditionally realized natural resource for food preservation. *Curr. Sci.* 110(10): 1890–92.

Qualls, W.A., Xu, R.D., Hott, J.A., Smith, M.L., Moeller, J.J. 2011. Field evaluations of commercial repellents against the flood water mosquito, *Psorophora columbiae* (Diptera: Culicidae) in St. Johns County, Florida. *J. Med. Entomol.* 48(6): 1247–49.

Raghuwani, B.R., Kapadia, M.N. 2003. Efficacy of different vegetable oils as seed protectants of pigeon pea against *Callosobruchus maculatus* (Fab.). *Indian J. Plant Prot.* 31(1): 115–18.

Ramanjaneyulu, A.V., Reddy, A.V., Madhavi, A. 2013. The impact of sowing date and irrigation regime on castor (*Ricinus communis* L.) seed yield, oil quality characteristics and fatty acid composition during post rainy season in South India. *Ind. Crops Prod.* 44: 25–31.

Ramos, L.C.D., Tango, J.S., Savi, A., Lcal, N.R. 1984. Variability for oil and fatty acid composition in castor bean varieties. *J. Am. Oil Chem. Soc.* 61: 1841–1843.

Rana, M., Dhamija, H., Prashar, B., Sharma, S. 2012. *Ricinus communis* L.—A review. *Int. J. Pharmtech. Res.* 4(4): 1706–11.

Ratnasekara, D., Rajapakse, R.H.S. 2009. Repellent properties of plant oil vapours in pulse beetle, *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae) in stored green gram (*Vigna radiata* Walp.). *Trop. Agric. Res. Ext.* 12(1): 13–16.

Salihu, B.Z., Gana, A.K., Apuyor, B.O. 2014. Castor oil plant (*Ricinus communis* L.): Botany, ecology and uses. *Int. J. Sci. Res.* 3(5): 1334–41.

Salimon, J., Noor, D.A.M., Nazrizawati, A.T., Firdaus, M.Y.M., Noraishah, A. 2010. Fatty acid composition and physicochemical properties of Malaysian castor bean *Ricinus communis* L. seed oil. *Sains Malaysiana* 39(5): 761–64.

Sanappa, M.B., Acharya, M.F. 2014. Efficacy of botanical oils in the control of cowpea bruchid, *Callosobruchus maculatus* Fab. in stored cowpea. *Pestology* 38(2): 44–47.

Saribiyik, O.Y., Ozcanli, M., Serin, H., Serin, S., Aydir, K. 2010. Biodiesel production from *Ricinus communis* oil and its blends with soybean biodiesel. *J. Mech. Eng.* 56: 811–16.

Severino, L.S., Auld, D.L., Baldanzi, M. et al. 2012. A review on the challenges for increased production of castor. *Agron. J.* 104(4): 853–80.

Shinde, P.S., Godase, S.K., Mule, R.S., Jalgaonkar, V.N. 2011. Use of some surface protectants against pulse beetle, *Callosobruchus maculatus* Fab. (Coleoptera: Bruchidae) infesting stored cowpea. *Pestology* 35(1): 38–43.

Silitonga, A.S., Masjuki, H.H., Ong, H.C., Kusumo, T.Y.F., Mahila, T.M.I. 2016. Synthesis and optimization of *Hevea brasiliensis* and *Ricinus communis* as feedstock for biodiesel production: A comparative study. *Ind. Crops Prod.* 85: 274–86.

Singh, A.S., Kumari, S., Modi, A.R., Gajera, B.B., Narayanan, S., Kumar, N. 2015. Role of conventional and biotechnological approaches in genetic improvement of castor (*Ricinus communis* L.). *Ind. Crops Prod.* 74: 55–62.

Singh, V., Yadav, D.S. 2003. Efficacy of different oils against pulse beetle, *Callosobruchus chinensis* in green gram, *Vigna radiata* and their effect on germination. *Indian J. Entomol.* 65(2): 281–86.

Sridhar, B.S., Binna, K.V., Anita, M.V., Paramjeet, K.B. 2010. Optimization and characterization of castor seed oil. *Leonardo J. Sci.* 17(9): 59–70.

Stubiger, G., Pittenauer, E., Allmaier, G. 2003. Characterization of castor oil by on-line and off-line non-aqueous reverse-phase high performance liquid chromatography-mass spectrometry (APCI and UV/MALDI). *Phytochem. Analy.* 14(6): 337–46.

Thomas, A., Matthaus, B., Fiebig, H.J. 2015. Fats and fatty oils. In *Ullman's Encyclopedia of Industrial Chemistry*, ed. B. Elvers, 1–84. Weinheim: Wiley-VCH Verlag.

Thomas, T.P., Birney, D.M., Auld, D.L. 2013. Optimizing esterification of safflower, cottonseed, castor and used cottonseed oils. *Ind. Crops Prod.* 41: 102–6.

Tunaru, S., Althoff, T.F., Nusing, R.M., Diener, M., Offermanns, S. 2012. Castor oil induces laxation and uterus contraction via ricinoleic activating prostaglandin EP3 receptors. *Proc. Nat. Acad. Sci. USA* 109(2): 9179–84.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2006. *Ricinus communis* L. castorbean. PLANTS Database. Baton Rouge: National Plant Data Center. http://plants.usda.gov.

Velasco, L., Rajas-Barros, P., Fernandez-Martinez, J.M. 2005. Fatty acid and tocopherol accumulation in the seeds of a high oleic acid castor mutant. *Ind. Crops Prod.* 22: 201–6.

Verma, R.K., Chaurasia, L., Kumar, M. 2011. Antifungal activity of essential oils against selected building fungi. *Indian J. Nat. Prod. Resour.* 2(4): 448–51.

Wale, M., Assegie, H. 2015. Efficacy of castor bean oil (*Ricinus calamus* L.) against maize weevils (*Sitophilus zeamais* Mots.) in northwestern Ethiopia. *J. Stored Prod. Res.* 63: 38–41.

Wani, A.H., Bhat, M.Y. 2012. Control of root-knot nematode, *Meloidogyne incognita* by urea coated with nimin or other natural oils on mung, *Vigna radiata* (L.) R. Wilczek. *J. Biopesticides* 5(Suppl.): 255–58.

Wani, A.H., Joshi, J., Titov, A., Tomar, D.S. 2014. Effect of seed treatment and packing materials on seed quality parameters of maize (*Zea mays* L.) during storage. *J. Appl. Res.* 4(4): 40–44.

Weiss, E.A. 2000. *Oilseed Crops*. 2nd ed. Oxford: Blackwell Scientific Ltd.

Wilson, R., van Schie, B.J., Howes, D. 1998. Overview of the preparation, use and biological studies on polyglycerol polyrecinoleate (PGPR). *Food. Chem. Toxicol*. 36: 711–18.

Yahaya, M.M., Bandiya, H.M., Yahaya, M.A. 2013. Efficacy of selected seed oils against the fecundity of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Experiment* 8(4): 513–21.

Yakubu, B.L., Mbonu, O.A., Nda, A.J. 2012. Cowpea (*Vigna unguiculata*) pest control methods in storage and recommended practices for efficiency: A review. *J. Biol. Agric. Healthcare* 2(2): 27–33.