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Castor (*Ricinus communis*): An Underutilized Oil Crop in the South East Asia

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Abstract

Castor belongs to a monotypic genus *Ricinus* and subtribe Ricininae. It is one of the oldest plants, getting importance as an agricultural crop for subtropical and tropical countries in the world. Castor is a hardy plant, requires low input, tolerates marginal soils, is easy to establish in the field, is resistant to drought, and gives yield 350–900 kg oil per hectare. Castor oil shows great functional value in energy sector, industry, and pharmaceutical. In recent years, it received increasing demand in the international market for its more than 700 uses, ranging from medicine and cosmetics to biodiesel, plastic, and lubricants. The oil is significant for many industrial uses compared with other oils from plant sources because of its high and low temperature-tolerant properties. This chapter has been written to provide botanical descriptions, ecology, agro-technology, and versatile industrial uses.

Keywords: *Ricinus communis*, biodiesel, underutilized crops, monotypic

1. Introduction

Castor (*Ricinus communis* L.) is a nonedible vegetable oil seed crop cultivated all over the world. It grows well in the wet tropics to the subtropical dry region with an optimum temperature of 20–25°C [1]. Though Ethiopia is considered as the probable center of origin, its cultivation is mostly concentrated in Asia, about 92.2% of the total production [2]. India is the largest producer and exporter of the castor oil (www.statista.com). Castor oil is an important feedstock for the chemical industry which is mostly utilized for biodiesel production and pharmaceutical application because it is the only commercial source of hydroxylated fatty acid [3]. It is also used for the production of lubricants, hydraulic and brake fluid, polymer materials, coating, fertilizer, soaps, waxes, and greases. The use of castor oil in Southeast Asian countries is limited due to its high cost of detoxification of castor meal and refining of castor oil. The plant also contains toxic compounds such as ricin, ricinin, and RCA (*Ricinus communis* agglutinin) [4]. The major challenges for castor production are the development of high-yielding varieties that will be non-shattering, dwarf, resistance or tolerance to disease and insect pests, and low ricin, ricinin, and RCA content. The development of easy method for the detoxification of

castor meal and refining of castor oil is also important. Castor oil has a great future potential for use in the production of biodiesel.

2. Castor plant

Castor (*Ricinus communis* L.) is a species of annual or perennial flowering plant which belongs to the spurge family Euphorbiaceae, monotypic genus *Ricinus*, and Riciniinae subtribe. It is a fast-growing and suckering shrubby tree which reaches the size of 5–12 m. It is commonly known as veranda (Bengali), arandi (Hindi), era-gach (Assamese), castor and castor oil plant (English), wonderboom (Dutch), ricin (French); Rizinus and Palma Christi (German), Fico d'inferno (Italy), and ricino (Portuguese).

3. Origin and distribution

Castor is generally distributed in tropical, subtropical, and warm-temperate regions of the world. It is very commonly found in fellow land, roadside, and compounds in rural and urban areas and also common along seasonally dry rivers in altitudes between 400 and 2700 m. The probable center of origin for castor is Northeastern Africa, i.e., Ethiopia and Somalia [5], and it has four centers of diversity, viz., (a) Ethiopian-Eastern African, (b) Northwest and Southwest Asia and Arabian peninsula (c), subcontinent of India, and (d) China [3]. It is currently naturalized across the African continent, the Atlantic coast to the Red Sea, Tunisia to South Africa, and islands in the Indian Ocean. It is also widely cultivated and naturalized in tropical and subtropical regions of America and Asia and temperate areas of Europe [6].

4. Botany and reproductive biology

4.1 Botany

Leaves: The long-stalked and simple glazing leaves are 15–45 cm long; alternate and palmate with 5–12 deep lobes with serrate leaf margins (**Figure 1**); lobes acuminate, membranous, oblong to linear; 1–3-cm-long stipules united to a sheathing bud, deciduous; and petiole 3.5–50 cm long, round [7].

Different leaf colors are observed in castor, which start off as dark reddish purple or bronze when young and turn into dark green, sometimes with a reddish tinge as they mature. In some varieties, the leaves are really green from the start, whereas in others, a pigment suppresses the green color of all chlorophyll-bearing parts, leaves, stems, and young fruits so that they remain a dramatic purple to reddish brown color throughout the whole life of the plant.

Flower: The flowers are burgeoned in an erect terminal panicle-like inflorescence, which consists of cymes, usually glaucous, later-appearing lateral by overtopping, up to 40 cm long. The flowers are unisexual, regular, with short pedicel, 1–1.5 cm in diameter; the calyx with 3–5 lobes; corolla absent; male flowers toward the base of the inflorescence with many stamens in branched bundles; and female flowers relatively few in number and remain toward the apex of the inflorescence with early caducous sepals, three-celled superior ovary, usually soft spiny, style 3, red or green, 2-cleft [7].

Fruit: Fruits are ellipsoid to subglobose, usually three-lobed smooth or spiny capsule (**Figure 2**), 1.5–2.5 cm long, brown, dehiscent in three cocci each opening by a vulva and one-seeded [8].

Seed: Seed is ellipsoid, 9–17 mm long, compressed with a brittle, mottled, glaring seed coat with distinct caruncle at the base, endosperm copious, white, and cotyledons thin [8].

Seedling: Seedlings are grown by epigeal seed germination; cotyledons petioled, broadly oblong up to 7 cm long, flat with entire margins; and first leaves opposite [8] (**Figures 1** and 2).

4.2 Reproductive biology

In angiosperms, the flowers are the reproductive structures which are most varied physically and show a correspondingly great diversity in the methods of reproduction. It reproduces by following a mixed pollination system, which prefers selfing by geitonogamy and, at the same, outcrossing by anemophily and entomophily. Under natural condition more than 80% cross-pollination occurs. Flowering may occur within 6 months after seed germination. The flowers of castor are normal monoecious, i.e., it bears pistillate flower on the upper part of the raceme and staminate on the lower part [9]. The proportion of pistillate and staminate flowers among racemes can vary both within and among genotypes and also influenced by the environment. The percentage of pistillate flowers in normal monoecious varieties is highest on the first racemes and decreasing subsequently on developed racemes. The number of staminate flowers is proportionally increased with the decrease in pistillate flowers [10]. The probable cause of this variation is mainly temperature in different season. Moderate temperature in spring and early summer promotes female flower, while high temperature in mid and late summer

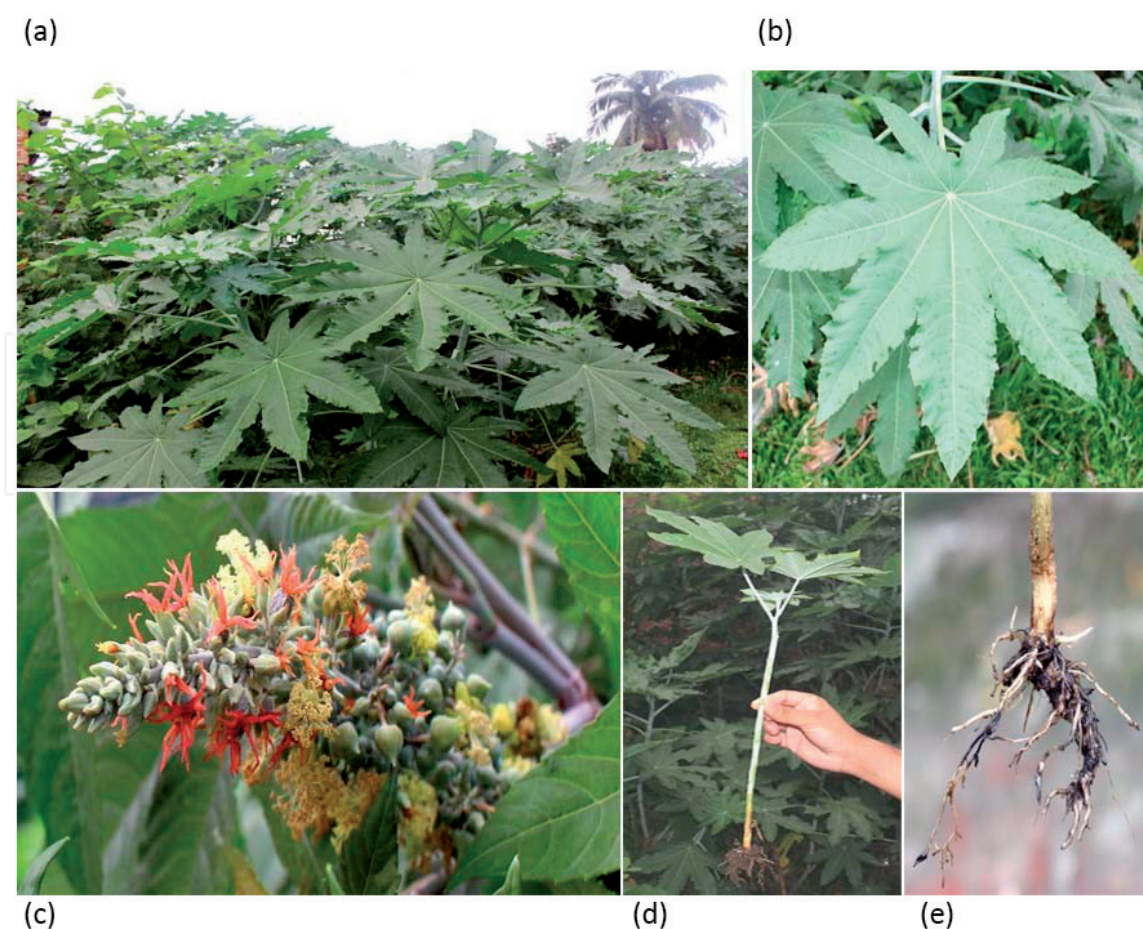


Figure 1.
(a) Castor plant, (b) leaf, (c) inflorescence, (d) seedling, (e) root. Source: The above pictures were collected from Habiganj, Sylhet, Bangladesh.

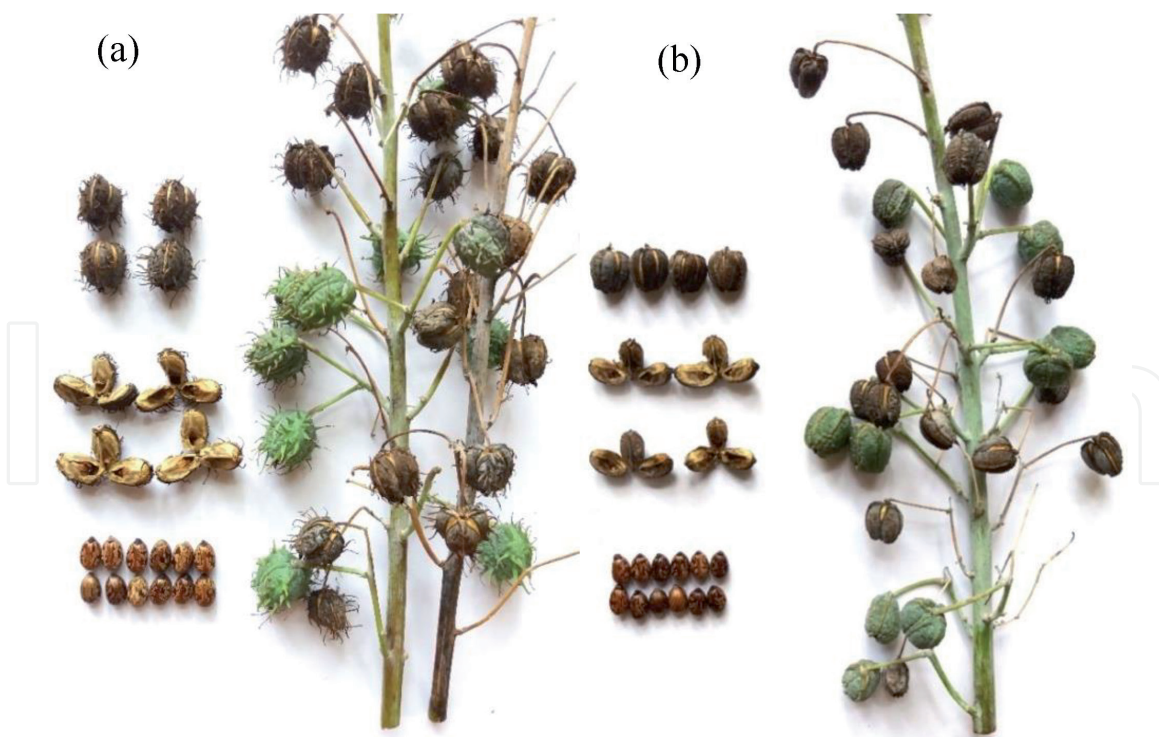


Figure 2.

Castor fruit and seeds, (a) spiny fruit, (b) spineless fruit. Source: the above pictures were collected from Habiganj, Sylhet, Bangladesh.

promotes male flower. Femaleness is highest in young plants with a high level of nutrition, and maleness is highest in older plants with a low level of nutrition [11]. After opening, a male flower releases viable pollen grains for 1–2 days, and shedding of pollen occurs in the morning. The temperature between 26 and 29°C and relative humidity of 60% is the best environmental conditions for pollen dispersal which may vary according to cultivar. Before the opening of the female flowers, male flowers reach its maturity, and anthesis usually occurs in a short period of time [12]. Therefore, the pistillate flowers that open and become receptive get a large source of pollen. After the opening of the flower, the stigma remains fully receptive for few hours, but there is a difficulty for pollination to occur promptly after the opening of the flower. Depending on the environmental condition, the stigma may remain receptive for 5–10 days [13].

5. Climate and soil

Castor, a ruderal species, can be grown in tropical and subtropical regions as a perennial plant and in temperate regions as annual plant. It is a long day plant, and for normal growth and development, a day length of about 12–18 hours is required. It is found from sea level to altitudes of about 2000 m with an optimum of 300–1500 m, and its cultivation is restricted to countries lying between 40°N and 40°S latitudes, but in Russia, a few varieties are grown even up to 52°N latitude [8], and in India it is being cultivated up to an altitude of 2500 m. Its cultivation is restricted up to 500 m where frost is common during cropping season. For obtaining better yield, a frost free-growing period of about 140–190 days is highly essential depending on variety. It is deep rooted and fairly drought-resistant crop which requires annual rainfall of 250–750 mm. A moderate temperature of 20–25°C [1] and low relative humidity with clear sunny days are highly favorable for better yield. For germination, a soil temperature of 12–18°C is suitable. It is sensitive to high relative

humidity and temperature above 40°C and below 15°C, which yields a negative impact on yield [14].

Castor can be grown well on fairly deep, moderately fertile, slightly acidic, and well-drained sandy loam soils. Heavy clays with poor drainage and marshy soils are not suitable for castor cultivation. The soil with low water holding capacity, pH > 9 and pH < 4, electrical conductivity (EC) > 4 dS/m, and exchangeable sodium percentage (ESP) > 20% is not suitable for castor cultivation. Moderately fertile soils are preferable than excessive fertile because excessive fertility favors vegetative growth in the expense of seed yield [14].

6. Cultivation technology

6.1 Land preparation

Land preparation is an essential step to prepare soil favorable for cultivation, to control weed, and to conserve soil moisture. Castor requires moist and well-pulverized loose top soil for better seed germination and early growth. It is done by three to four deep plowings followed by two to three harrowing to break the clods and leveling the field. Ridging is recommended in dry areas where the total rainfall is low [8].

6.2 Seed rate, spacing

To cover one hectare of land, a seed rate of 10–12 kg is recommended, but it varied upon cultivars and sowing method. The seed rate will be 8–10 kg/ha for hand dibbling and for intercropping; it depends on sowing proportion component crops. The spacing of castor plantation varies with growth habit, duration of variety, and sowing time. Early and medium duration cultivars are sown at a closer spacing of 90 cm × 45 cm, and long duration cultivars are sown at a wider spacing of 90 cm × 60 cm under rainfed condition. 90 cm × 60 cm spacing is favorable under irrigated condition. However, under late sown situation, a narrow spacing (60 cm × 60 cm) is practiced to realize higher yields [14].

6.3 Propagation and sowing

Castor is generally propagated through seeds and sown during June and July. However, it can be cultivated year-round under irrigated condition. Under rainfed conditions, the seeds are sown by plow furrow, and the seeds are dibbled by maintaining proper spacing under irrigated condition. The emergence of seedling is easy due to its epigeal seed germination behavior. Deep sowing (8–10 cm) is recommended in light soils under rainfed conditions, and shallow sowing (6–8 cm) is preferable under irrigated condition and heavy soils [14].

6.4 Irrigation

Although castor can tolerate moisture stress, it performs well to irrigation. If castor expertizes moisture stress during seedling to flowering stage, it shows poor performance. If irrigation facilities are available, two to three irrigations should be given during this critical stage. If only one irrigation is available, it should be given at flowering stage. No irrigation should be given during maturity stage because it delayed maturity and also influences new vegetative growth [14]. During the season of high rainfall, proper drainage facilities should be provided to avoid water stagnancy.

6.5 Weed management

Weed management is the most important intercultural operation in any crop cultivation as it impacts on overall yield by competing for nutrients, fertilizer, manure, light, and water. The critical period of crop-weed competition is the 50–60 days after sowing (DAS). After land preparation by deep plowing followed by harrowing, the crop needs two weeding and hoeings either manually or mechanically at 25 and 50 days after sowing. Chemical control like weedicides is also effective in controlling weeds. Preplant incorporation of fluchloralin or pre-emergence application of pendimethalin at 1 kg/ha is an effective control measure of grasses and broad-leaved weeds. One of these weedicide along with one hoeing at 50 days after sowing may be effective in controlling weeds in castor [14].

6.6 Cropping and intercropping

As castor is a tall statured crop, it is being cultivated as shade crop for turmeric and also grown as trap crop for pests. It can be cultivated as sole crop in rotation with wheat and linseed. Groundnut, black gram, green gram, sorghum, pearl millet, cowpea, pigeon pea, and cotton can be grown along with castor. Intercropping of castor with pigeon pea extenuate the occurrence of *Spodoptera litura* [14]. In rainfed condition, intercropping of castor with green gram or black gram in a 1:2 ratio and, in irrigated condition, intercropping of castor with onion in a 1:2 ratio by maintaining 1.5×1 m spacing are recommended.

6.7 Manures and fertilizers

The application of manures and fertilizer in appropriate time and dose assured better crop growth and yield. More fertilizers are required for hybrids and irrigated crop than variety and rainfed crop. Before final land preparation 15–20 t/ha well-decomposed farm yard manure (FYM) should be applied in both irrigated and rainfed condition for supplying nutrients as well as for moisture conservation. Under rainfed condition, the recommended dose of both N and P_2O_5 fertilizers is 40 kg/ha. At the time of sowing, all P fertilizer with 50% N fertilizer should be applied, and the remaining N fertilizer should be top dressed after first weeding. Under irrigated condition, both P_2O_5 and K_2O are required at a dose of 40 kg/ha, and N fertilizer may be required at 150 kg/ha. These N fertilizers should be applied at three splits at sowing, first hoeing and preflowering stages. As a source of P fertilizer, single superphosphate is more preferable because Ca and S fertilizers are also applied [14].

6.8 Pest and diseases control

Capsule borer (*Dichocrocis punctiferalis*) and semilooper (*Achaea janata*) can be controlled by dusting BHC 10% in early stages or spraying 0.1% carbaryl on the crop. To protect the crop from seedling blight, water logged and low-lying areas should be avoided. To prevent the occurrence of root rot and *Alternaria* blight, castor seed should be treated with thiram or agrosan GN at 3 g/kg seed. In the latter stage of *Alternaria* blight of castor, foliar application of carbamates or copper-based fungicide may be effective. In preventing castor wilt, treatment with carbendazim + *Trichoderma* at 10 g/kg seed + soil application of *Trichoderma* has been found most effective. Seed treatment with *Trichoderma viride* and FYM and neem cake application has also found effective in decreasing the occurrence of *Alternaria* blight [14].

6.9 Harvesting and threshing

The annual type of castor requires about 4–9 months to mature depending on the variety, and the perennial type may continue bearing for 10–15 years. Improved varieties with non-shattering capsule should be harvested as soon they are fully dry, but shattering type capsules are harvested when the capsule turn greenish to yellowish [8]. The central spike on the main rachis matures first than the spike on side branches start maturing. Therefore, two to three pickings may be needed for harvesting the crop because all the spikes do not mature at the same time. Harvesting of immature capsules should be avoided as it has negative impacts on oil content. After harvesting, the capsule should be sun dried for 4–5 days, and finally threshing and winnowing are done by manually or mechanically [14].

6.10 Yield

The yield of castor may vary from 1 to 3 tons of seed/ha depending on agroclimatic conditions, crop management practices, and the hybrid or variety used [8]. The percentage of oil is 37% and seed cake 63%.

7. Genetics and breeding

Naturally all forms of castor are diploid and its chromosome number is $2n = 2x = 20$ [15]. In nature, crossing of castor occurs freely and produce fertile progeny. Commonly 5–50% outcrossing occurs naturally, but in some dwarf cultivars, it may be ranged 90–100%. Male-sterile and female-sterile lines have been also identified which have a great value in breeding improved varieties [7]. Due to highly outcrossing nature, a great phenotypic variation is observed in characters such as stem color, epicuticular wax (bloom wax), plant height, presence of spines in capsules, branching behavior, leaf shape, sex expression, seed color, and response to environmental condition [16, 17]. It is also possible to exploit genetic polymorphism for quantitative traits in breeding programs [18, 19]. Mass selection of castor is effective when the traits under selection are highly heritable. This selection technique performs more effectively with self-fertilization of selected plants to impede cross-pollination and controlled selection technique to minimize environmental variation [20]. It is also an effective technique for increasing the frequency of pistillate castor plants of the NES type [21]. Cultivars developed by mass selection are Kavkazskaya (in the former USSR), IAC-38 and BRS Energia (in Brazil), and Conver and Kansas (in the United States) [22, 23]. Back cross method has been used to transfer monogenic traits such as dwarf plant stature, spineless capsules, stem color, bloom, non-shattering, plant height, and resistant to wilt. Pedigree selection has been used to select high-yielding families and individual plant within the families. Subsequent progeny test for oil content and resistant to *Fusarium* wilt was done by Fernández-Martínez and Velasco [22] and developed wilt resistant cultivar Fioletovaya. Individual plant selection followed by progeny test was used to develop cultivar Guarany in Brazil [24]. In India, several cultivars with tall and late maturation such as HC 1 to HC 8, EB 16 A, EB 31, S-20, Junagadh 1, Punjab castor 1, Rosy, and MC 1 were developed by using this method [25]. Recurrent selection has effectively decreased the plant height in the cultivar Guarani by successive cycle of selection and recombination of selected lines or individual plants [26, 27]. Hybridization involving single, double, or triple crosses

is being used to combine desired traits from different sources. The first commercial hybrid of castor was GCH 3 which was developed in India [3]. A number of other castor cultivars exist to which “Hale” and “Lynn” are dwarf cultivars in the United States, mainly used as pollen parent in hybrid production. Other well-known cultivars are “Rica” and “Venda” in France and “T-3,” “CS-9,” “SKI-7,” and “GCH” series of hybrids in India [8].

8. Castor seed

8.1 Oil composition

Castor oil is the mostly used and economically important seed oil in the world. Castor seed comprises about 40–55% oil, and kernel contains 64–71% oil which is the highest among all cultivated oil crops (**Table 1**). Castor oil is a unique vegetable oil due to high ricinoleic acid content (84.2–94%) which is a monounsaturated and 18-carbon fatty acid. Ricinoleic acid is exceptional from other fatty acids because it has a hydroxyl functional group on the 12th carbon that makes it more polar than other fats. The chemical reactive capacity of the alcohol group also approbates chemical derivatization that is almost impossible with other seed oils. Castor oil is a valuable chemical in feedstock due to its ricinoleic acid content and underling a high price than other seed oils. Besides ricinoleic acid content, some other fatty acids are present in castor oil, which are presented in **Table 2**.

Salimon et al. [34] identified five major triacylglycerol in castor seed oil. These were triricinolein (RRR), diricinoleoylstearyl-glycerol (RRS), diricinoleoyl-oleoyl-glycerol (RRO), diricinoleoyl-linoleoyl-glycerol (RRL), and diricinoleoyl-palmitoyl-glycerol (RRP). They also first reported the per cent composition of triacylglycerol present in castor seed oil (**Table 3**) by using high performance liquid chromatography (HPLC) with evaporative light scattering detector (ELSD).

Crops	Average seed oil percentage	Oleic acid	Linoleic acid	Linolenic acid	Ricinoleic acid
Nonedible oil crop					
Castor	40–55%	2–6%	1–5%	0.5–1%	85–95%
<i>Jatropha</i>	35–40%	21.8–44.7%	31.49–47.8%	0.2%	—
<i>Pongamia pinnata</i>	30–40%	44.5–71.3%	10.8–24.75%	2.9–6.3%	—
Edible oil crop					
Canola	42%	57.59–61.41%	15.3–22.3%	10.8–13%	—
Linseed	38%	20.6–23.6%	19–22%	41.9–53.1%	—
Sunflower	48%	27–36%	52–67%	—	—
Soybean	18%	27.3–29.7%	43–56%	4.6–11.4%	—
Palm	52%	20.3–24.7%	0.7–1.8%	—	—

Source: Yadava et al. [28]; Islam et al. [29]; Karmee and Chadha, [30]; Shrirame et al. [31]; Kostik et al. [32]; Islam et al. [33].

Table 1.
Oil composition of castor and other vegetable oil.

Name of acids	Carbon number	Average percentage range
Saturated fatty acid	—	1–2.5%
Unsaturated fatty acid	—	97.5–98.3%
Ricinoleic acid	18:1	84.2–95%
Oleic acid	18:1	2.8–5.5%
Linoleic acid	18:2	4.3–7.3%
Linolenic acid	18:3	0.2–0.5%
Stearic acid	18:0	0.9–1.2%
Palmitic acid	16:0	0.7–1.3%
Dihydroxystearic acid	18:0	0.3–0.5%
Others	—	0.2–0.5%

Source: Salimon et al. [34]; Conceição et al. [35]; Gupta et al. [36].

Table 2.
Average fatty acid composition of castor seed oil.

Triacylglycerol	Composition (%)
Triricinolein (RRR)	84.1
Diricinoleylstearoylglycerol (RRS)	8.2
Diricinoleyloleoylglycerol (RRO)	5.6
Diricinoleyllinoleoylglycerol (RRL)	1.2
Diricinoleylpalmitoyl-glycerol (RRP)	0.9

Source: Salimon et al. [34].

Table 3.
Major triacylglycerols and their composition in castor seed oil.

9. Physical and chemical properties of seed oil

The physical and chemical properties of castor oil includes moisture content, density, refractive index, fire point, flash point, smoke point, cloud point, pour point, viscosity, color, pH, turbidity, lipid content, free fatty acids, acid value, saponification value, unsaponifiable matter, peroxide value, iodine value, cetane number, and calorific value, and their probable range is presented in **Table 4**. The difference in the value of these properties may be due to environmental factor which influences the growth and productivity of the seed. The moisture content of the crude oil lies between 0.2 and 0.31%, which indicates low moisture content that is the characteristics of good shelf life. The density ranges between 0.946 and 0.950 g/cm³, which can be further reduced by esterification for application as biodiesel. The refractive index indicates the level saturation of the oil. The fire point, flash point, smoke point, cloud point, and pour point give evidence of good combustion quality as biofuel. The viscosity range (0.305–0.545 cps) indicates that the oil is light and highly unsaturated. The low levels of pH (5.8) notify the presence of modest amount of free fatty acid in the oil, which is a good indicator for utilization of oil in soap making. The free acids and acid value express the level of oxidative deterioration of the oil through enzymatic or chemical oxidation. However, the fatty acids can be transformed to edible oil through refining of crude oil and will also improve its quality for industrial use. The saponification value (182.9–327.4 mgKOH/g) expresses the relative length of fatty acid chain.

Properties	Average value range
Moisture (%)	0.2–0.31
Density (g/cm ³)	0.946–0.950
Refractive index at 25 C	1.47
Fire point (°C)	254.8–257.2
Flash point (°C)	222.9–227.1
Smoke point (°C)	214–216
Cloud point (°C)	3
Pour point (°C)	2
Viscosity (cps)	0.305–0.545
pH	5.8
Turbidity	4–6
Lipid content (%)	43.3–47.8
Free fatty acids	3.4–7.21
Acid value (mg/g)	4.9–14.42
Saponification value (mgKOH/g oil)	182.9–327.4
Unsaponifiable matter	3.4
Peroxide value (meq/kg)	10.2
Iodine value (wiji's value)	57.93–59.35
Cetane number	55.9
Calorific value (MJ/Kg)	36.25

Source: Salimon et al. [34]; Nangbes et al. [37]; Bale et al. [38]; Saifullah et al. [39].

Table 4.
Physicochemical properties of castor seed oil.

Abayeh et al. [40] reported that oil with high saponification value could be used as raw materials for soaps and cosmetics. Iodide value could be used to determine the total number of double bond present in the oil, which indicates the susceptibility of oil to oxidation. The peroxide value appraises the rancidity of the oil during storage process. Cetane number indicates the ignition quality, and calorific value represents the measures of available energy of fuel. All of these physical and chemical properties of castor oil established it as a good source of lubricant and biofuel and to be used for industrial purpose.

10. Toxic properties

The endosperm of castor seed contains a group of closely related toxic glycoproteins (ricin), ricinoleic acid, and the alkaloid ricinin. The seed cake of castor contains the toxic compound ricin, but castor oil does not contain ricin because it is insoluble in oil, and if remains it can be expelled in the refining process [3]. The toxic properties of castor seeds had been noticed since ancient times and its toxicity to human has recently been reported [41, 42]. Castor seed were used in classical Egyptian and Greek medicine and were delineated in Sanskrit medicine (Sushruta Ayurveda) from the sixth century BC [41]. More than 750 cases of accidental or deliberate intoxication have been reported in human [43]. The lethal dose in adults may be considered as four to eight seeds, but children are susceptible to small amount of seeds. An acceptable

rate (0–0.7 mg/kg body weight) of daily castor oil consume for man has been established by the combined Food and Agriculture Organization (FAO) and World Health Organization (WHO) Expert Committee on Food Additives. Ricin creates health problem by damaging the ribosomes, which produce all of the protein needed by a cell and if the proteins cannot be produced cell may dies [4]. The symptom of ricin ingestion may be appeared up to 36 hours but generally start within 2–4 hours. This symptom includes a burning sensation in the mouth and throat, abdominal pain, diarrhea, fever, nausea, vomiting, incoordination, drowsiness, and hematuria. Severe dehydration, drop in blood pressure, and reduced urination have occurred within several days. If immediate treatment is not taken, vascular collapse and death may occur within 3–5 days; however, in most patients, full recovery can be possible [43].

The other toxic protein in castor seed is RCA (*Ricinus communis* agglutinin) which agglutinates red blood cells. When RCA is injected into the blood stream, it causes a person's blood to coagulate [4]. Toxicity also occurs in animals when they ingest broken seed or break the seed by chewing, but intact seed does not release toxin, it passes through the digestive tract [44]. Toxicity may vary to different animal at different dose. The toxin produced from castor seed is also used as natural insecticide and fungicide.

11. Uses of castor oil and its derivatives

11.1 Medicinal and pharmaceuticals

11.1.1 Antimicrobial activity

Ricinus communis shows antimicrobial activity against dermatophytic and pathogenic bacterial strains such as *Streptococcus progenies*, *Staphylococcus aureus*, as well as *Klebsiella pneumonia* and *Escherichia coli*. The result revealed that the petroleum ether and acetone extract inhibit microbial activity, whereas ethanolic extract has antibacterial activity only on higher concentration [45]. Different solvent extracts of root of *Ricinus communis* (200 mg/ml) occupy antimicrobial activity by utilizing well diffusion method against pathogenic microorganism such as *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella typhimurium*, *Proteus vulgaris*, *Bacillus subtilis*, *Candida albicans*, and *Aspergillus niger*. The hexane and methanol extracts possess highest antimicrobial activity, while aqueous extracts have no significant antimicrobial activity [46].

11.1.2 Antioxidant activity

It is concluded that seed extract of castor shows significant antioxidant activity by using lipid peroxidation method by ferric thiocyanate and free radical scavenging effect on 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) and hydroxyl radicle produced from hydrogen peroxide. Those diseases which are caused by oxidative stress can be reduced by high antioxidant function of *Ricinus communis* seeds at low concentration. Methyl ricinoleate, ricinoleic acid, 1,2-octadecadienoic, and methyl ester are the chemical compound present in castor for which it shows antioxidant activity [47]. The leaf and stem extract of castor contains flavonoids, which show antioxidant activity [48, 49].

11.1.3 Antiulcer activity

The oil that is extracted from the seed of *Ricinus communis* has the potentiality to prevent ulcer at a dose of 500 mg/kg and 1000 mg/kg, but 1000 mg/kg is more effective against ulceration caused by pylorus ligation, aspirin, and ethanol in rats.

It is shown that the antiulcer activity of *Ricinus communis* is due to the cytoprotective action of drug or corroborant of gastric mucosa that ameliorate the mucosal protection [50].

11.1.4 Antidiabetic activity

Ethanollic extract of root of *Ricinus communis* shows significant effect in reducing the glucose level of fasting blood. An experiment was conducted on diabetic rats that showed that the glucose level was reduced from an initial level of 386 ± 41 mg/dl to 358 ± 33 , 293 ± 28 , 191 ± 25 , 133 ± 29 , 96 ± 20 , and 79 ± 16 mg/dl on the 2nd, 5th, 7th, 10th, 15th, and 20th days, respectively. The fasting blood glucose became normal on the 20th days. Castor showed statistically similar result in alkaline phosphatase, serum bilirubin, creatinine, serum glutamate oxaloacetate transaminase, serum glutamate pyruvate transaminase, and total protein which was observed even after the administration of the extract at a dose 10 g/kg body weight. The extraction is also effective for total lipid profile and liver and kidney functions. Thus, *Ricinus communis* is considered as a powerful phytomedicine for diabetics [51].

11.1.5 Anti-inflammatory and free radical scavenging activity

The methanolic extract of castor root possesses anti-inflammatory and free radical scavenging activity. It was studied in Wistar albino rats in which oral administration of methanolic extract at a dose of 250 and 500 mg/kg body weight showed significant ($p < 0.001$) anti-inflammatory activity in carrageenin-induced hind paw edema model. The oral administration of the extract at the dose 500 mg/kg body weight also showed significant ($p < 0.001$) anti-inflammatory activity in cotton pellet granuloma model. The methanolic extract also showed free radical scavenging activity by suppressing lipid peroxidation initiated by carbon tetrachloride and ferrous sulfate in rat liver and kidney homogenates. The extract augments the free radical scavenging activity of stable radical 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), nitric oxide, and hydroxyl radical in in vitro assay methods [52].

11.1.6 Central analgesic activity

The crude extract of root bark of castor possesses analgesic activity in tail flick response model to radiant heat at a dose of 250 mg/kg [53]. The ethanollic extract of fruit pericarp of castor contains typical CNS stimulant and neuroleptic effects. The stimulant effects such as exophthalmus, hyperreactivity (evidence by tremors or by the pinna and grip strength reaction), memory improvement, and clonic seizures seem to be due to the presence of alkaloid ricinine, which is considered as a main toxic compound in the extract. Animals that died after being treated with extract showed similar signs; they all died by clonic seizures, which were followed by apparent breathing arrest. On the other hand, compounds other than ricinine may cause neuroleptic-like effects of extract because ricinine is not responsible for reducing locomotor function or catalepsy in mice [54].

11.1.7 Anticancer activity

In spite of being a poisonous compound, ricin possesses the potentiality to prevent tumor and has been used in cancer research and chemotherapy during

recent years. One of the most important uses of ricin is in the manufacturing of immunotoxins where the protein ricin is jointed to monoclonal antibodies. In vitro technique was used to produce these antibodies which have a protein receptor site that identify the specific target cells in the tumor. The protein antibody joined together and resulting compound is known as immunotoxin. For the treatment of a cancer patient, the deadly toxin can be carried at the site of tumor by arming these antibodies with ricin. Thus, castor has the most significant use in the treatment of tumor or cancer cell due to the presence of ricin. It kills only the target tumor cell without damaging other in the patient [55].

11.1.8 Antifertility activity

The methanolic extract of seeds of castor plant has a positive preliminarily phytochemical test for steroid as well as alkaloids. The pituitary gland releases gonadotropins by both positive and negative feedback mechanism due to sex hormones, and also the pituitary gland inhibits the release of luteinizing hormone and follicle-stimulating hormone. This is due to estrogen and progesterone fall a cumulative effect in luteal phase of menstrual cycle. Thus, it helps the inhibition of maturation follicle in the ovary and prevents ovulation. As sex hormone is a steroidal compound, methanol extract of castor seed contains steroids; it produces antifertility effect [56, 57].

11.1.9 Lipolytic activity

The compound ricin show lipolytic function by using different substrates such as (a) one analogue of triacylglycerol, BAL-TC₄ (b), different chromogenic substrates such as *p*-NP esters of aliphatic short to medium chain acids, and (c) monomolecular films of a pure natural diacylglycerol, DC₁₀, in emulsion and in a membrane-like model. An experiment was conducted that revealed that ricin of *Ricinus communis* acts as lipase and possesses the ability to hydrolyze different lipid classes as well as phospholipid (important constituent of cellular membrane). The lipolytic activities are maximum at pH 7.0 in the presence of 0.2 M galactose. The action of ricin on membrane phospholipid occurred by phospholipase A1 activity which may be regarded as minor activity of lipase [58].

11.1.10 Hepatoprotective activity

The ethanolic leaf extract of castor at 250/500 mg/kg body weight possesses hepatoprotective activities. This is because of their inhibitory activities of an increase in the function of serum transaminase, level of liver lipid per oxidation, protein, and glycogen, and the activities of acid and alkaline phosphatase in the liver initiated by carbon tetrachloride (CCl₄) are increased. The extract also treated the depletion of glutathione level and adenosine triphosphatase functions in the CCl₄-induced rat liver. Flavonoids are present in the ethanolic extract which possess membrane-stabilizing and antiperoxidative effects. *Ricinus communis* also increases regenerative and reparative ability of liver because of the presence of flavonoids and tannins. Duo to the presence of N-demethyl ricinine in the leaves of *Ricinus communis*, it showed anticholestatic and hepatoprotective activity against paracetamol-induced hepatic damage. The whole leaves of *Ricinus communis* have the potentiality to defend against liver necrosis and fatty changes generated by CCl₄, while the glycoside and cold aqueous extract give protection against liver necrosis and fatty changes, respectively [59–62].

11.1.11 Wound healing activity

Castor oil is effective for injury healing. It produces antioxidant activity and inhibits lipid peroxidation. The compound, which is responsible for inhibiting lipid peroxidation, is supposed to increase viability of collagen fibrils by increasing the strength of collagen fibers, increasing the circulation, and preventing cell damage by promoting DNA synthesis. Tannins, flavonoids, triterpenoids, and sesquiterpenes have astringent and antimicrobial properties, which repair wound portion and increase the epithelialization. An observation showed that castor oil healed the wound area by reducing the scar area and epithelialization time in excision wound model. A comparison study showed that 10% w/w concentration has better wound healing property than 5% w/w concentration [63].

11.1.12 Anti-asthmatic activity

There are some compounds present in the root extract of castor plant which is very important for the treatment of asthma, because it has anti-allergic and cell-stabilizing ability. Saponins present in the extract possess mast cell-stabilizing effect, and flavonoids have smooth muscle relaxant and bronchodilator function. The apigenin- and luteolin-like flavonoids normally restrict basophil histamine release and neutrophils beta glucuronidase release and show anti-allergic activity in vivo. Another study showed that ethanolic extract of *Ricinus communis* reduces milk-induced leukocytosis and eosinophilia and possesses anti-asthmatic activity as flavonoids and saponins are present [64].

11.1.13 In vitro immunomodulatory activity

The immunomodulatory compound generally increases the immune response of the human body against different pathogens by activating the nonspecific immune system. The phagocytosis is the engulfment of microorganisms by leucocytes which is one of the main protective mechanisms of the organism. The final step of phagocytosis is the intracellular killing of microorganism by the neutrophils. The leaves of *Ricinus communis* contain tannins, which increase the phagocytic function of human neutrophils and thus produce immunomodulatory effect [65].

11.1.14 Bone regeneration activity

Experiments were conducted to see the biocompatibility and potentiality of *Ricinus communis* polyurethane (RCP) to regenerate the bone. Result revealed that *Ricinus communis* polyurethane is mixed with calcium carbonate and phosphate which promote matrix mineralization and are biocompatible materials [66]. The biological properties of RCP are improved by incorporating alkaline phosphate to it with subsequent incubation in synthetic body fluid [67]. The benefit observed in RCP as compared to demineralized bone is that the former has slow reabsorption process [68].

12. Lubricants, hydraulic, and brake fluid

Castor oil has been used to develop low pour point lubricant base stocks by synthesizing acyloxy castor polyol esters [69]. Due to having low pour point property, it provides full lubrication to the equipment in cold environment [70]. An interesting study by Singh revealed that castor oil-based lubricant has the luscious potentiality to be used as smoke pollution reducer. In his research he used a biodegradable

two-stroke (2 T) oil, which is a popular variety of lubricating oil and was used on two-stroke engines in scooters and motorcycles. The lubricant comprises tolyl monoesters and performance additives but no miscibility solvents. The result revealed that it decreased smoke by 50–70% at a 1% oil/fuel ratio [71]. Castor oil also can be used as car engine lubricant. A modified version of castor oil lubricant comprising 100 parts of castor oil and 20–110 parts of a chemically and thermally stable, low viscosity blending fluid, soluble in castor oil showed its potential to be used as a lubricant for refrigeration system [72]. In spite of having its use as DOT 2 rating brake fluid, castor oil lubricant is considered as obsolete types of brake fluid and is not used in the modern vehicles [73].

13. Food

Food grade castor oil is used in the food industry. It can be used as food additives such as flavor and food color and as a mold inhibitor and in packaging. In the food-stuff industry, polyoxyethylated castor oil is also used [74]. The white, large seed of castor are an important source of food condiment called “Ogiri” in the southeastern part of Nigeria [75].

14. Polymer materials

For synthesizing the renewable monomers and polymers in the castor oil and its derivatives are used [76]. To produce the vulcanized and urethane derivatives, castor oil was polymerized with sulfur and diisocyanates, respectively [77]. In other study, by sequential mode of synthesis, full-interpenetrating polymer networks (IPNs) were prepared using epoxy and castor oil-based polyurethane (PU) (Raymond and Bui [78]). Similar to the aforementioned study, a series of two components IPN of the modified castor oil-based PU and polystyrene were prepared by sequential method [79]. IPN is also known as polymer alloy and is considered as one of the fastest growing research areas in the field of polymer blends in the last two decades [79]. As a root-end filling material, castor oil polymer has been shown to possess sealing ability. Root-end filling material is the root-end preparation filled with experimental materials, and it provides an apical seal to prevent the bacterial movements and its diffusion from root canal system to peripheral tissues [80]. One of the most common applications using castor oil is biodegradable polyesters [81]. The first synthetic condensation polymers are polyesters which are environmentally safe and friendly. This is also useful in biomedical field as well as elastomers and packaging materials [82, 83]. Castor can be combined with other monomers with a view to produce an array of copolymers. Again these copolymers provide materials with different properties which find use in products ranging from solid implants to in situ injectable hydrophobic gel [81].

15. Preparation of soap, waxes, and greases

Castor oil is used to produce soaps and waxes [30]. In a study by Dwivedi and Sapre [84], they utilized castor oil in total vegetable oil greases. Total vegetable oil greases are those in which both lubricant and gallant are formed from vegetable oil. In their study, they utilized a simultaneous reaction scheme to produce sodium and lithium greases from castor oil.

16. Coating

Castor oil can be used in producing coatings and paints. For useful paintings and furniture oil application, castor oil is dehydrated by monoconjugated oil-maleic anhydride adducts [85]. Castor oil is utilized as coating application by converting the hydroxyl functionalities of castor oil to β -ketoesters using *t*-butyl acetoacetate [86]. Advanced surface coating materials were synthesized from castor oil-based hyperbranched polyurethanes (HBPU) which is a highly branched macromolecule [87]. Most recently, Allauddin et al. [88] synthesized a high-performance hybrid coating by using a methodology that consists of introducing hydrolyzable-Si-OCH₃ groups onto castor oil that have been used for the development of PU/urea-silica hybrid coating.

17. Fertilizer

There are two by-product produced from the castor seed, i.e., husks and meal. Lima et al. [89] reported that the blend of castor meal and castor husks can be used as fertilizer, which is effective for substantial plant growth when it is applied up to a dose of 4.5% (in volume) of meal. But when the dose exceeds 4.5%, the plant growth is retarded and even the plant may die [89].

18. Other uses

Besides the above uses, the *Ricinus communis* is used for different purposes. The oil is used in coating fabrics and other protective covering, in the production of typewriter and printing inks. Castor oil is also used in textile dyeing. The hydrogenated oil is useful for the production of polishes, carbon paper, candles, crayons, etc. The cellulose from stem is used to prepare cardboard, paper, etc. Polyoxyethylene hydrogenated castor oil is also useful for the manufacture of vitamin A and vitamin C, eye drop, and oral nitroglycerine sprays [90].

19. Biodiesel production from castor oil

19.1 Castor oil extraction

The extraction of castor oil from castor seed can be done by either mechanical pressing or solvent extraction or a combination of both. After harvesting, the seeds are dried to split open the seed hull so that kernel can be collected easily. Extraction process starts with the dehulling of seeds, and this can be done either manually by hands or mechanically with the help of a castor seed dehuller. After dehulling the seed, foreign materials such as sticks, stems, leaves, sand or dirt are removed by using a series of revolving screens or reels. After cleaning, the kernels are heated in a steam jacketed press to eliminate moisture, and then these cooked kernels are dried; this hardening will help in extraction.

19.1.1 Mechanical extraction

A hydraulic press or oil expeller is used to remove oil from castor kernels. This mechanical extraction is done at low temperature which recovers only about 45% oil from the castor seeds. Higher temperature can increase the extraction efficiency

up to 80% of the available oil which can be done by using high-temperature hydraulic press. The extraction temperature can be maintained by circulating of cold water through the pressing machine that is responsible for cold pressing of kernels. Cold-pressed castor oil contains low acid and iodine content and is lighter in color than the castor oil which is solvent extracted. After extraction, the oil is collected and filtered, and the filtered materials are mixed with fresh kernels for repeat extraction. The extraction process is repeated for several times by bulking of filtered material with new material and oil is collected. The by-product is finally removed from the press as seed cake. This seed cake contains about 10% of castor oil [1]. The remaining oil in seed cake can be obtained by crushing the seed cake and subjected to solvent extraction.

19.1.2 Solvent extraction

The solvent extraction of castor oil can be done by using Soxhlet extractor. About 300 ml of solvent such as hexane, heptane, or petroleum ether is poured in a round-bottom flask, and 10 g of crushed castor kernel packed with oil tissue or filter paper is placed in a thimble and inserted into the center of the extractor. The extractor then is fixed on the round-bottom flask, and a condenser is placed on the top of the extractor. Then the fitted apparatus is placed in a heating mantle and heated (50–60°C) to boil the solvent. When the solvent starts to boil, the vapor rises through the vertical tube into the condenser at the top. The vapor condensed and dripped into the thimble at the center. The extract seeps through the pores of the thimble and fills the siphon tube where it flows back down into the round-bottom flask [91]. The extraction process is continued for 8 hours, and after that, the extract with solvent in the round-bottom flask is subjected to rotator evaporator to recover the solvent from the extracted oil. The weight of extracted oil should be recovered for further determination.

19.2 Transesterification

The transesterification process is the reaction of a triglyceride with an alcohol to produce ester and glycerol. A triglyceride has a glycerine molecule as its base with three long chain fatty acids annexed. The characteristics of the fat are determined by the nature of the fatty acids subsumed to the glycerine which affects the characteristics of the biodiesel. In the production of biodiesel, vegetable oil in the form of triglycerides reacts with small chain alcohol (methanol, ethanol, propanol, etc.) in the presence of homogeneous catalyst such as base (KOH, NaOH) or acid (HCl, H₂SO₄, H₃PO₄) or heterogeneous catalyst as zeolites or biocatalyst as enzymes. The process is also called alcoholysis. When methanol is used, it is called methanolysis, and esters that are produced in methanolysis are called fatty acid methyl esters (FAMES), and in case of ethanol, the process is termed as ethanolysis, and the esters produced in this process are called fatty acid ethyl esters (FAEEs) [92]. The transesterification is a reversible reaction, so alcohol must be added in excess to ensure the reaction in the right direction (**Figure 3**).

19.2.1 Procedure

For transesterification about 25 ml of oil was kept in three-necked round-bottom flask and heated to 65°C. Then, the required quantity of methanol and catalyst (KOH) is added with stirring system. The experiment was continued for 3 hours and then the sample was monitored by running TLC to ensure the completion of reaction. After cooling, two layers were differentiated by separatory funnel, the

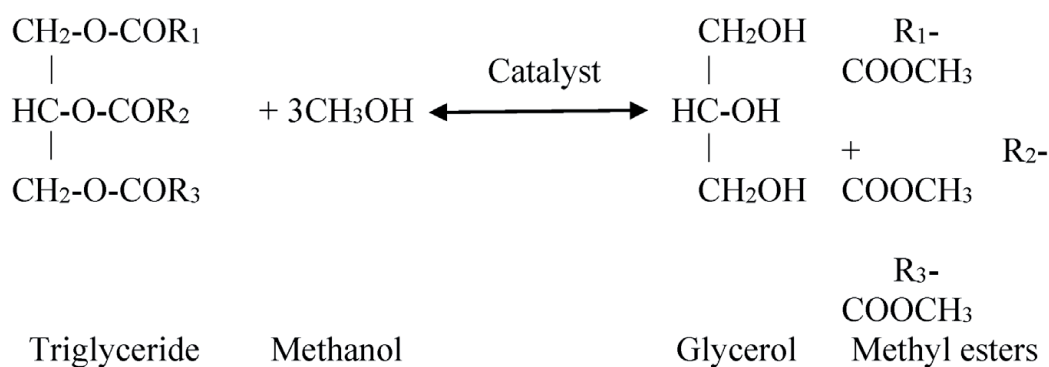


Figure 3.
Transesterification reaction.

upper layer is methyl ester (biodiesel), and the lower layer is glycerol. Produced methyl ester could be purified by successive rinse with 2.5% (w/w) H_2SO_4 and distilled water. NaCl was used to avoid emulsion during washing process. The washed methyl ester should be treated with anhydrous sodium sulfate to eliminate excess water. It was then filtered and dried by heating at low temperature (60°C) for 30 minutes [93].

19.3 Filtration or purification

After extraction of oil by using oil expeller, there still remain impurities in the extracted oil which can be removed through filtration process. Large- and small-sized particulates, any dissolved gases, acids, or even water can be removed by using filter press. Crude oil of castor seed is pale yellow or straw in color, but it can be made colorless or near colorless by refining and bleaching. The crude of castor seed also has a discrete odor which can also be deodorized during refining process [1].

19.4 Refining

Following filtration of crude oil of castor, it is subjected to refining process to eliminate impurities such as colloidal matter, phospholipids, excess free fatty acids, and coloring agents. Removal of these impurities prevents deterioration during long-term storage. The refining process includes several steps such as degumming, neutralization, bleaching, and deodorization, and sometimes winterization should be performed for efficient oil refining [1].

19.4.1 Degumming

Degumming is performed to reduce the phospholipids and metal content of the crude oil of castor. The forms of phospholipids found in crude castor oil are lecithin, cephalin, and phosphatidic acids [94], and these phosphatides can be classified as hydratable and nonhydratable [95]. For efficient removal of these phosphatides, a suitable degumming procedure such as water degumming, acid degumming, and enzymatic degumming has to be implemented. Generally crude vegetable oil contains about 10% of nonhydratable phosphatides [95] which may vary depending on several factors such as type of seed, quality of seed, and condition applied during milling operation. Water degumming process can be followed to remove hydratable phosphatides, and nonhydratable phosphatides can only be eliminated by applying acid or enzymatic degumming procedures [95].

19.4.2 Neutralization

Neutralization is the process of removing excess free fatty acids (FFAs) from the degummed oil. The FFA content is high in old seeds, which are stored for more than 1 year with high moisture content [96]. The degummed castor oil is refined by chemical refining or alkali neutralization which abates the content of FFAs, oxidation products of FFAs, residual proteins, phosphatides, carbohydrates, traces of metals, and a part of pigments. The alkali neutralization is done by treating degummed castor oil with an alkali solution (2% caustic soda) at temperature between 85 and 95°C with continuous stirring for about 45–60 minutes [97]. At this stage the alkali reacts with FFAs and converts them into soap which has a higher specific gravity than the neutral oil and tends to settle at the bottom. The oil can be differentiated either by gravity separation or by using commercial centrifuges. The separated oil is then washed with hot water to remove soap, alkali solution, and other impurities [98]. For batch neutralization of castor oil, it needs four to six times hot water wash so as to reduce the level of soap below 100 ppm [97]. The oil, thus obtained, is dried in vacuum dryer and transferred to the bleaching process.

19.4.3 Bleaching

After degumming and neutralization, the castor oil that appeared is clear and liquid, but it may still contain colored bodies, natural pigments, and antioxidants (tocopherols and tocotrienols). However, bleaching, an adsorption process, is used to remove such colored pigments and phospholipids. Bleaching of castor oil can be done under vacuum at about 100°C, and continuously stirring the oil with appropriate amount activated earths and carbon [91]. The activated earths are clay ores that consist of minerals such as bentonite and montmorillonite. About 2% bleaching earth and carbon are required in the bleaching process to produce desirable light-colored oil. In this process, colored particles, soap, and phosphatides are adsorbed by the activated earth and carbon. A commercial filter is used to remove the activated earth and carbon. The spent earth and carbon thus obtained contains about 20–25% oil content [99]. This retained oil in earth can be recovered by boiling the spent earth in water or by solvent extraction method. The oil that is recovered from the spent earth is highly colored with high FFA and high peroxide content usually more than 10 mg KOH/g and 20 meq/kg, respectively [100].

19.4.4 Deodorization

Deodorization is vacuum distillation processes that carry away relatively volatile components that produce undesirable flavor, color, and odors in fat and oils. To produce pharmaceutical grade castor oil, deodorization is necessary, but in other cases, this process is not essential as it is a nonedible vegetable oil [101, 102]. Deodorization is generally under high vacuum and temperature above 250°C to expel undesirable odor caused by ketones, aldehydes, sterols, triterpene alcohols, and short chain fatty acids [98]. Pharmaceutical grade castor oil is deodorized under low temperatures (150–170°C) and high vacuum for 8–10 hours to hydrolysis of hydroxyl group ricinoleic acid [103].

19.4.5 Winterization

Most vegetable oils contain high concentration of waxes, fatty acids, and lipids which is subjected to winterization before final use. Winterization is the process

where waxes are crystalized and eliminated by a filtering process to avoid clouding of liquid fraction at cooler temperatures [1].

20. Challenges

20.1 Development of high-yielding varieties

For the development of high-yielding varieties of castor understanding, the genetics of economically important traits is most important. Different morphological and qualitative traits are controlled by one or few genes and their additive, dominant, and epistatic effects, which make it more difficult to develop high-yielding varieties. Stem color of castor is controlled by epistatic interaction of two genes “M” and “G” [104] and tall plant shows dominance over dwarf plant due to a monogenic factor. Particularly the inheritance of sex expression is important in the development of hybrids. There are three types of pistillate line, i.e., N, S, and NES, which could be used for hybrid production. In the N type, the occurrence of only female flowers is controlled by a recessive gene (ff); in the S type, the production of only female flower is controlled by a polygenic complex with dominant and epistatic effects; and in the NES type, the induction of female is also controlled by a recessive gene (ff), but sexual reversion occurs when the air temperature is more than 31°C [105–107]. The seed yield and seed oil content are usually inherited by quantitative manner. Some important characters such as the number of nodes before flowering, number of racemes per plant, and seed oil content are controlled by additive genetic effect [108, 109]. Other traits such as length of primary raceme, number of capsules per racemes, and seed weight are also additively inherited [110–112]. Early maturity is another important character for castor cultivation in tropical areas or regions of short growing seasons where multiple crops are cultivated, but it shows negative correlation with high seed yield which is the main hindrance in the development of early maturing variety [113]. Genetic transformation of castor also remains challenging as it is averse to proficient regeneration of durable and transformed plant. The callus culture of castor for regeneration of plant has been problematic due to the lack of proper protocol which restricted the development of transgenic cultivars [114]. The most important global challenge in castor breeding is the development of cultivars that facilitate mechanical harvest. The success of perennial and indeterminate type castor is limited than annual and determinate type. The selection dwarf and non-branching type castor plant is hardly possible due to high genotype versus environment interaction.

20.2 Disease and pests

The most important challenges in castor cultivation are management of disease and pest incidence. Several disease occurrences were noticed in castor; among these gray mold (*Botryotinia ricini*), vascular wilt (*Fusarium oxysporum* f. sp. *ricini*), and charcoal rot (*Macrophomina phaseolina*) are the major diseases. Some other disease causes epidemic condition depending on the genotype and environmental conditions such as the leaf spot caused by the fungus *Alternaria ricini* and *Cercospora ricinella* and the bacteria *Xanthomonas axonopodis* pv. *ricini*. Among these *Alternaria ricini* is the most important because it is a seed-borne disease and causes seedling blight and pod rot with the loss of seed yield up to 70% [3]. Several plant parasitic nematodes are noticed on castor, but they do not cause severe damage [115]. Among these reniform nematodes, *Rotylenchulus reniformis* is the most important because it predisposes castor to the infection of *Fusarium oxysporum* [116]. Gray mold is

considered as the most serious disease worldwide, but a few studies have been conducted recently on this disease [117]. Resistant varieties cannot be developed through breeding programs, but a few genotypes moderately tolerant to this disease have been identified [5]. Further studies have been needed for the management *Botryotinia ricini*. The occurrence of vascular wilt can be managed through varietal resistance, seed treatment, and crop rotation. Charcoal rot or *Macrophomina* root rot can be managed through cultivar resistance, but crop rotation and organic matter rectification can abate the severity of this disease [118].

The major insect pests that cause significant damage are castor semilooper (*Achaea janata*), castor shoot borer (*Conogethes punctiferalis*), capsule borer (*Dichocrocis punctiferalis*), tobacco caterpillar (*Spodoptera litura*), red hairy caterpillar (*Amsacta* spp.), and leaf miner (*Liriomyza trifolii*) [16, 119]. In Brazil, the major insect pests of castor are stink bug (*Nezara viridula*); leafhopper (*Empoasca* spp.); defoliator including armyworm (*Spodoptera frugiperda*), semilooper (*Achaea janata*), and black cutworm (*Agrotis ipsilon*); and the mites *Tetranychus urticae* and *Tetranychus ludeni* [120, 121]. Cotton lace bug (*Corythucha gossypii*) was also noticed as a pest of castor in Colombia. The integrated pest management program with pesticides and crop rotation, insect traps, neem extract can be used to manage the insect pests of castor [119].

21. Detoxification of castor product

After the extraction of oil from castor seed, it produces castor meal as a by-product, which contains a toxic compound ricin. This ricin content is about 1 to 5% of the weight of the castor meal remaining after oil extraction [122, 123]. Small quantities of castor meal can be easily detoxified, but no commercial or industrial level detoxification process has been successfully implemented yet. In early 1934, it was demonstrated that by boiling for 2 hours, castor meal could be detoxified. Several other methods for castor meal detoxification have been investigated later which includes short but repeated boiling, autoclaving, steam heating, fermentation, ionizing radiation, and mixing castor meal with tannin-rich meal of Sal seed (*Shorea robusta*) and the addition of sodium hypochlorite, alkali, or acid substances [3]. Both ricin and allergens was detoxified simultaneously by adding calcium hydroxide followed by extrusion [124]. At present, the addition of lime is the simplest and effective method of ricin detoxification. Probably the high pH is responsible for the denaturation of ricin [125–127]. The economics and access to commercial castor production can be improved through the development of industrial process of castor detoxification, but the impediment is high-energy costs for processing the meal, decreased in feed quality of processed meal, and the absence of proper methods to promptly and cheaply quantify the residual ricin in the meal [3].

22. Present status

According to FAOSTAT, during 2014, the average world production of castor oilseed was 1.95 million tons that was harvested from an area of 1.44 million hectare, of which 92.2% was concentrated in Asia, mostly in India. India ranked first in the production of castor oil seed that was about 1.73 million tons followed by Mozambique (0.069 million ton), China (0.04 million ton), Brazil (0.038 million ton), and Myanmar (0.011 million ton). In Bangladesh, it is only 266 tons, which is too much lower compared to India, Mozambique, and China. India is the highest exporter of castor oil accounting for more than 90% of the castor oil exports, while the United States, European countries, and China are the major importer, accounting for more

than 84% of the imported castor oil [128]. Harvested area, production, and yield of the top 10 castor oil seed producers during 2014 are presented in **Table 5**.

23. Future prospects

The global consumption of castor is increased, but the current production of castor is not increasing at sufficient rate. Future research strategies play an important role in the world production of castor. International collaboration between scientific communities is needed for the development of solution to the main constraints to castor production, processing, and marketing. Although some locally adapted variety and hybrids are developed, an integrated plant improvement strategy needs to be developed for further progress. A closer interaction between plant breeders, molecular biologists, plant pathologists, plant physiologists, and entomologists is needed for speeding up the research activities. Both the quality and quantity of castor oil can be improved by using biotechnological innovations and genetic engineering. The castor genome draft should be used as map for introducing molecular markers in castor breeding. Improved coordination of germplasm bank helps in the standardization of evaluation method and increase the exchange of accession in breeding programs. The development of non-shattering, dwarf, and high-yielding cultivar with additional improvement in machinery and agronomic practices will allow the prompt transition of castor to mechanized production [129]. Breeding of castor for resistance or tolerance to disease and insect pest is also important for the production of good-quality castor oil seed. Another major concern is the development of castor cultivar with low ricin, low ricinin, low allergen, and low RCA content [41, 42, 130]. Accurate detection and detoxification of castor toxin in feed and biological samples remain a challenge to the commercial use of castor meal in animal rations. The use of castor oil for biodiesel production is problematic due to its high viscosity and high cost of production and refining. However, castor has a tremendous potentiality as a source of bioenergy and industrial feedstock with high oil content, unique fatty acid composition (ricinoleic acid), and a wide range of adaptation under drought and saline condition.

Country	Harvested area (million hectare)	Production (million ton)	Yield (ton/ha)
India	1.04	1.733	1.666
Mozambique	0.184	0.069	0.375
China	0.046	0.040	0.870
Brazil	0.063	0.038	0.591
Myanmar	0.014	0.011	0.782
Ethiopia	0.005	0.011	2.000
Paraguay	0.008	0.009	1.125
Vietnam	0.008	0.007	0.875
South Africa	0.010	0.006	0.607
Angola	0.016	0.004	0.253

Source: FAO [2].

Table 5.
Harvested area, production, and yield of the top 10 castor oil seed producers during 2014.

24. Conclusion

Castor is an underutilized nonedible oil crop species that has a variety of application, but it is promising for its high oil content particularly as a potential source of renewable energy. It is also used in the production of pharmaceuticals, lubricants, hydraulic and brake fluid, polymer materials, coating, and fertilizer. It also contains toxic compounds that are ricin, ricinin, and RCA. The development of high-yielding varieties, detoxification castor meal, and control of insect pests are the major challenges.

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Conflict of interest

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