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A review of the chemical composition, modification, and biomedical application of *Ricinus communis*

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According to research, the use of fuels based on plant oil is replacing fuels based on petroleum as we move towards renewable resources. In comparison to fossil fuels, natural oils like castor oil offer competitive physicochemical properties. Natural oils are renewable, inexpensive, and environmentally friendly, which has sparked much research interest in their use. Vegetable oils are much more in demand for domestic and industrial uses due to the growing global population. Vegetable oils derived from plants have been noted as having a high nutritional value. Castor plant seeds are among those with high oil content because of their high unsaturated fatty acid content and bioactive components. Its fatty acid composition primarily consists of ricinoleic acid, with a small amount of stearic, palmitic, and also oleic acids. Because ricinoleic acid in castor oil is distinct from all other oils (vegetable), it is preferred for an ample range of applications. Castor oil contains a variety of minor biological substances, such as phytosterol, tocotrienol, tocopherol, phenolic components, phospholipids, and carotenoids. Since bio-oils are versatile, they may be utilized in various sectors, including electronics, food, paper and agriculture. Castor oil may be utilized in various grades and has many derivatives. For various applications, bio-binders are regarded as the material with the most potential. Therefore, this study summarises the physical and chemical characteristics of castor oil, its composition, the process used to create different castor oil derivatives and its uses.

Keywords: Biodiesel, Carotenoids, Castor oil, Ricinoleic acid, Tocopherol

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Introduction

Tropical East Africa's Ethiopian region is home to the castor bean plant, *Ricinus communis* (*R communis*). In recent years, it has spread to tropical and high-temperate zones throughout the world. *R communis* can be found in well-drained soil in hot temperate locations that have enough nutrients/ minerals and sufficient moisture to support the plant's growth, including riverside, flood, and other hotbeds. With enough heat, sunlight, and moisture, the castor plant can reach a height of 2–5 meters in a single season[1]. It resembles a tropical aralia and has enormous leaves that can reach a width of 50 cm. Along with the wild variety, a number of variants of CO are cultivated with a range of leaf hues, including black-purple, dark red metallic, bronze-green, maroon, bright green with white veins, and plain green. Female flowers are found slightly above the male flowers for most of the year in dense terminal clusters of blooms[2,3]. Each female flower has no petals and consists of an ovary, which is small and spiny in nature. Furthermore, it turns into a fruit or seed and is covered with feathers to give it brightly coloured structures. The castor seed is made up of approximately three pieces (carpel), which get detached at maturity. The single seed is embedded inside each carpel, and as the seed matures, the carpel opens up, releasing the seed (seed power). Castor seed is obtained from wild plants and is grown for commercial purposes on plantations[4,5]. Fig. 1a–c depicts the castor plant, as well as whole and dehulled seed. India ranks first in the global castor trade, with a projected production of 1.598 million metric tonnes and a total anticipated cultivation area for the crop of approximately 0.696 million hectares in 2021–2022[6]. Gujarat is the main castor-producing state in India, whereas the castor crop is also grown in many states. Depending on the land, climate, and other factors, production differs from state to state. According to a

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Fig. 1 — a) Castor plant; b) whole; and c) dehulled seed.

review of the literature, the main parts of the castor plant are the seeds, which weigh 468 kg; the stem, which weighs 388 kg; and the leaves, which weigh 144 kg per tonne of castor plant[7]. The stem and leaves of castor plants contain the most lignocellulosic biomass (25-40%), whereas castor seeds contain 30 to 45% oil and 15 to 20% protein. CO's widespread use has given castor seeds increased significance. In view of increasing worldwide interest in castor oil, this review summarizes the global scenario of chemical composition, the method of preparation of derivatives of castor oil, and the applications of its derivatives.

Chemical composition of castor oil (CO)

CO is mostly made up of neutral lipids and fatty acids (triglycerides). The oil also contains a small amount of other biologically active substances, such as tocotrienols, tocopherols, phenolics, phytochemicals, and carotenoids. These elements, as well as the nutritional advantages of CO, which have been studied by many researchers, are covered in the subsections that follow.

Triglycerides (TAG)

Three ricinoleic acid (RA) molecules are connected to a glycerol in the structure of most of the triacylglyceride (TAG) observed in castor oil[8-10]. Only five triacylglycerides were discovered in CO along with their content in an investigation by Salimon and colleagues: diricino-leoystearoyl (RRS, 8.2%), diricino-leoyloleoyl-glycerol (RRO, 5.6%), diricino-leoyllinoleoyl-glycerol (RRL, 1.2%), diricino-leoylpalmitoyl-glycerol (RRP, 0.9%), and major one is triricinolein (RRR-84.1%)[11]. Additionally, two separate investigations indicated that the RRR was the most prevalent TAG with 70% and 63%, respectively[12,13]. Triacylglyceride composition of vegetable oils is influenced by a number of variables, including the region of production, cultivation, oil extraction procedure, harvesting period, and storage period[12,14]. Therefore, these elements may be responsible for the triacylglyceride composition (%) in castor. Additionally, some tetraacylglycerols found in CO includes: (12-ricinoleoyl-ricinoleoyl)-ricinoleoyl-linoleoyl-glycerol (RRRL), (12-ricinoleoyl-ricinoleoyl)-

Table 1 — Chemical composition of castor oil[8,42-44]

S. No	Composition		Percentage	Reference
	Class of compounds	Name of compound		
1	Fatty acid	Ricinoleic acid	87.7-90.4	8
		Oleic acid	2.2-3.3	8
		Linoleic acid	4.1-4.7	8
		Palmitic acid	0.8-1.1	8
		Stearic acid	0.7-1.0	8
		Linolenic acid	0.5-0.7	8
2	Triglycerides	Triricinolein	88.9	42
		Trilinolein	4.9	42
		Triolein	3.5	42
		Tripalmitin	1.4	42
		Triestearin	0.9	42
		Trilinolein	0.3	42
3	Tocopherols	Alpha-tocopherol	2.84	43
		Beta-tocopherol	1.35	43
		Gamma-tocopherol	52.73	43
		Delta-tocopherol	43.09	43
4	Tocotrienols	Alpha-tocotrienol	0.24-0.42	44
		Beta-tocotrienol	0.47-0.61	44

ricinoleoyl-palmitoyl-glycerol (RRRP), (12-ricinoleoyl-ricinoleoyl)-ricinoleoyl-oleoyl-glycerol (RRRO), (12-ricinoleoyl-ricinoleoyl)-ricinoleoyl-stearoyl-glycerol (RRRS), and (12-ricinoleoyl-ricinoleoyl)-ricinoleoyl-linolenoyl-glycerol (RRRLn) HPLC was used to determine these acylglycerols, and only 3% of the CO's total acylglycerols included polyhydroxy fatty acids, compared to 0.5% for each individual acylglycerol[14].

Fatty acids

Fatty acids in plants have long been recognized. In 1848, Saalmülle published the first description of the fatty acid composition of CO and gave the term RA to an isolated hydroxyl acid. CO's main constituent is the monounsaturated fatty acid RA (C18:1-OH)[15]. Its chemical formula is $C_{18}H_{34}O_3$, and it has an eighteen-carbon straight chain with a single double bond at the twelfth position[16]. Later investigations revealed that CO includes a variety of fatty acids, including stearic acid (C18:0), palmitic acid (C16:1), oleic acid (C18:1), linolenic acid (C18:2), and linolenic acid (C18:3)[15,17] (Table 1 and Fig. 2). Vegetable oils contain linolenic and oleic acids, which are very good for human health and have been used to cure a number of ailments like diabetes, melanoma, kidney and heart disorders (high blood pressure, and high cholesterol levels)[18]. Because it resists oxidation, oleic acid can be employed to enhance the activities of antioxidants and as agents that prevent polymerization[19]. It can be conjugated with other essential oils and paired with antioxidants (such as tocopherols) to prevent oxidation because they have certain beneficial effects on the skin; linoleic, palmitic, and stearic acids are utilized widely in the beauty industry[18]. In the formulation of cosmetics and shampoos; some stearic acid esters such as ethylene glycol, glycol stearate, and glycol distearate are added to the formulation of cosmetic and shampoos to improve their pearly appearance or to provide more efficient cosmetic items[20]. The presence of these fatty acids in CO suggests that this plant has nutritional and industrial benefits.

Phytosterols

One of the insignificant bioactive substances found in the unsaponifiable portion of CO is phytosterols[21]. 4-desmethylsterols were discovered to make up much to 93.8% of the phytosterol class in castor, and β-sitosterol was the most prevalent component, approximately 47.1%[22]. Additional 4-desmethylsterols discovered were campesterol, stigmasterol, and Δ-5 avenasterol. CO also contains around 98.1 mg of phytosterol compound per 100 g of CO[23]. Castor sterols were studied by Sbihi *et al.*, who came to the conclusion that β-sitosterol is the primary sterol present in it[21]. Some researchers found no cholesterol in the oil samples, suggesting that the proportion of cholesterol was as low as 0.09%[23,24]. Temperature, cultivation, and planting location all affect phytosterol concentration; higher levels were found when

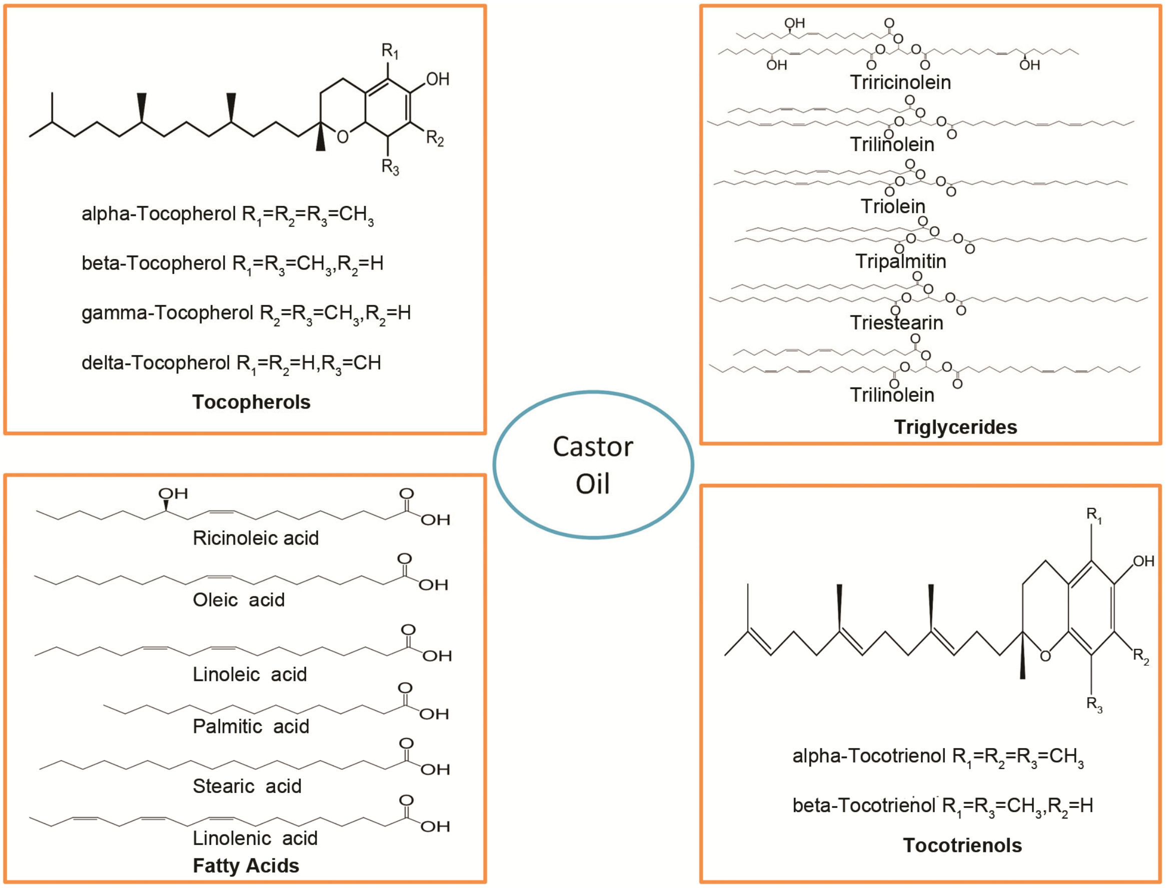

Fig. 2 — Chemical structure of various components of castor oil.

temperatures were higher[25]. CO is mainly used for industrial purposes; however, the residue from the refining of raw oil can be used to extract phytosterols. In this case, the production of high phytosterol-content castor cultivars may help to produce valuable co-products along the chain. Due to the fact that they lower serum levels of low-density lipoprotein cholesterol, phytosterols are essential in the human diet[23]. They are highly recommended as components for a wide variety of fortified meals.

Phospholipids

Phospholipids are one type of lipid that creates lipid bilayers in the cell membrane. Tocopherols and phospholipids may work together to postpone the onset of lipid oxidation[26]. The pharmaceutical and food sectors can benefit from knowing more about phospholipids, especially when used as emulsifiers.

The overall amount of polar lipids in castor, according to Moreau *et al.*, was found to be less than 1%, which includes phosphatidylcholine, phos-phatidylinositol, and phosphatidylethanolamine[27]. Phosphatidylcholine, which made up 30% of them, was the most common. Donaldson also noted that 2-day-old castor seed had 2% phospholipid, and the values for the various phospholipid classes were comparable[28]. The phospholipid levels observed in castor are lower than those of other seed oils, such as chufa nuts, which have 5.4%[29]. Dark-coloured oils typically have high phospholipid concentrations. Thus, because of the low concentration of phospholipids in the oils, CO has a clear, pale yellow tint.

Tocopherols and Tocotrienols

Free radicals are neutralized by lipid-soluble antioxidants like the tocopherols found in oil seeds. *In vitro* and *in vivo* tocopherol isomers exhibit various levels of antioxidant activity. Tocopherols, also known as Vitamin E homologues, have antioxidant action *in vitro* that protects the oxidation of unsaturated fatty acids; however, *in vivo* tocopherols are also known to protect the proliferative and cellular oxidation[30]. Many oilseeds, including castor, that contain α, β, γ, and δ tocopherols all have natural origins but differ in their chemical structure and subsequently have differences in antioxidant effects[31].

When Velasco *et al.* looked into the qualitative analysis of castor seed, they discovered that the oil included all of the tocopherol isomers. The primary isomers of tocopherol present in the CO were also δ- and γ-tocopherol[23,24]. It is commonly known that -α tocopherols are generally homologues of vitamin E, and both - δ and -γ tocopherols are powerful antioxidants (*in vitro*)[31]. These tocopherols may be responsible for the oil's wide shelf life, stability and anti-inflammatory effects in CO. Additionally, tocopherols regulate the membrane activities by preventing the oxidation of body lipids and organelle membranes as well as lowering personal risks for developing diseases, including neuronal disorders (Alzheimer's disease), cancer, and cardiovascular disorders. Tocopherol's presence, therefore, suggests that CO may be effective in preventing certain illnesses.

In addition to tocopherols, tocotrienols, which are members of the Vitamin E family and have the analogues α- and β-, are also naturally occurring antioxidants in oils. Tocotrienols have neuroprotective qualities and stop the synthesis of cholesterol[32]. When tocotrienols are unsaturated, they can be recognized. A few researches that had been done on the tocotrienol content of CO suggest that the predominant tocotrienols present in the oilseed are α- and β-tocotrienols[22,23].

Phenolic substances

Secondary metabolites from several categories are present in phenolic substances. This substance has one or more -OH groups attached directly to the aromatic ring[33]. The three main categories of dietary phenolic substances are tannins, phenolic acids, and flavonoids. The two principal subclasses of phenolic acids are hydroxycinnamic acid and hydroxybenzoic acid[26]. Gallic, syringic, and vanillic acids are byproducts of hydroxybenzoic acids, which primarily have aromatic rings with C1-C6 structure[34]. With regard to hydroxycinnamic acids, their derivatives with a C3-C6 structure include caffeic, ferulic, and p-coumaric acids[32]. Varied oils have different phenolic component types and contents. The flavour and antioxidant properties of oils are influenced by phenolic substances.

Methanol-ether was employed by Chakravartula *et al.* to isolate and extract the phenolic components from the dried and defatted castor seeds. Five acids were identified by HPLC-SPD chromatogram analysis: ferulic acid, syringic acid, *O*- & *p*-coumaric acid and cinnamic acid. The polarity and structural similarity of the various phenolic acids in castor determine how they can be separated. Compared to the separation of ferulic and syringic acid, *o*-and *p*-coumaric acid, and cinnamic acids, ferulic acid and p-coumaric acid were simple to resolve. CO has also been found to contain some more phenolic components, including chlorogenic, gallic, gentistic, and protocatechuic acid[34]. CO extracts phenolic chemicals differently depending on the extraction procedure and, moreover, the area of tissue under examination. Recent studies found that ethanol offered the highest total phenolic content of castor root extracts with 135.06 mg GAE/g, followed by the lowest phenolic content observed in ethyl acetate extracts and hexane extract, i.e., 50.24 and 25.50 mg GAE/g, respectively[35].

Phytochemicals

Momoh *et al.* evaluated CO's antibacterial and phytochemical activity, and the results showed that, in descending order, flavonoid, glycoside (cyanogenic), saponin, oxalate, alkaloid, and tannin were present[36]. Fitranda *et al.* also reported phytochemicals in CO by testing the *in vitro* antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* bacteria[37]. According to Gutiérrez-Grijalva *et al.*, the presence of flavonoids in plants implies that they have antibacterial, antioxidant, anti-inflammatory, and other therapeutic effects[38]. Tannin has some antibacterial and antiviral properties and is poisonous to fungi, yeast, and bacteria[37]. The antibacterial properties of CO may be caused by the presence of these phytochemical substances. In addition to their purgative and anti-inflammatory effects, more research is needed to increase their usage by pharmaceutical enterprises to manufacture antibiotics.

Carotenoids

Oils contain carotenoids, which function as antioxidants (scavenge free radicals) and may support the functioning of fat-soluble vitamins like vitamin A. While β-carotene alone can stop lipid oxidation, although tocopherol and β-carotene present in the CO may contribute to antioxidant activity.

CO's carotenoid content ranges from 12.34 to 39.47 mg/kg of β-carotene[39]. Another study found that CO contained 2.05 mg/kg of carotenoids. In contrast to other oils (vegetable), the carotenoid content of CO is superior to safflower 1.21 mg/kg, and soybean 0.37 mg/kg of oil. The oil's low carotenoid content may be because carotenoids break down more readily at higher temperatures[40].

Table 2 — Specification of castor oil according to Bureau of Indian Standards (BIS)[45]

S. No.	Characteristics		BIS Values			
		ASTM Values	First Grade	Medicinal	Commercial	Cosmetics
1	Colour	-2 max	30c	3.5c	40c	4.0c
2	Appearance	Transparent	Transparent	Transparent	Transparent	Transparent
3	Solubility in alcohol	Complete	-	-	-	-
4	Viscosity	6.3-8.9	-	-	-	-
5	Optical rotation	-	-	+3.5	-	-
6	Specific gravity	0.957-0.961	0.954-0.960	0.954-0.960	0.954-0.960	0.954-0.960
7	Refractive index	1.476-1.477	1.47-1.477	1.47-1.474	1.47-1.474	1.47-1.474
8	Loss on heating/ loss on drying	0.3 max	-	-	-	-
9	Acid value	2.0 max	4.0	2.0	6.0	2.0
10	Iodine value	83-88	82-90	82-90	82-90	82-90
11	Acetyl value	-	143	143	143	143
12	Saponification value	176-184	177-185	177-185	177-185	177-185
13	Hydroxyl Value	160-168	-	160	-	-
14	Moisture and volatile content %	-	0.25	0.25	0.25	0.25
15	% Unsaponifiable matter	0.7 max	1.0	0.8	1.0	0.8

Additionally, it has been discovered that carotenoids are related to the colour of oils, which is a key indicator of their quality[26]. Using a Lovibond tintometer to determine the colour of CO, it gives higher yellow value which suggests light colour of oil[40]. CO's light yellow hue indicates the presence of carotenoids, a yellow pigment. This colouring aids in absorbing UV rays[41].

Physico-chemical properties

The castor oil is clear in appearance. Castor oil is thick/ viscous, making it more stable at elevated temperatures (Table 2). The oxidative stability of the castor oil (1.1 at 110°C) is found to be low enough, which is caused by –OH groups and unsaturation (double bonds) that are likely to be broken into saturated compounds, leading to the formation of volatiles. Due to the fact that oxidation is more likely to occur in acidic oils, the oil’s fatty acid content also contributes to its low oxidative stability. CO also has a very low cloud point, which implies that no waxes have solidified and prevent oil from thickening, clogging pumps and injectors, and/or filters in processing facilities. Castor oil can be used in very cold climates for biodiesel applications due to its lower cloud point and high flash point, which renders it less flammable and, therefore, easy and safe to handle and transport.

Method of preparation and current applications of CO derivatives

Polymerized CO (Blown CO)

CO may be used to manufacture oils of different viscosities by introducing air or oxygen at temperatures between 80°C and 1300°C, with or without a catalyst. The process is called oxidative polymerisation. The oil thickens and gains specific gravity as a result of becoming more viscous. Inks, hydraulic fluids, lacquers, adhesives, and leathers all employ blown CO as a plasticiser, which might replace phthalates[46]. The polycondensation reaction is used to synthesise polyesters and polyamides. Due to the presence of RA in CO (which may be produced by hydrolysis), polyesters can be synthesised through polycondensation of the carboxyl and hydroxyl (–OH) groups in the fatty acid (Fig. 3). Poly-ricinoleate may have a unique feature due to the alkane chains that are present in it. This polyester's double bond may be further functionalised by a number of processes, including bromination, crosslinking, and hydroxylation, making it ideal for a wide range of applications[47].

Sebacic acid and 10-hydroxydecanoic acid are two examples of hydroxy acids that may be produced from RA and employed as monomers in the manufacture of polyesters. CO-derived sebacic acid may be utilised straight away to synthesise polyesters. By using alkoxycarbonylation to single-step functionalise and polymerise undec-10-ene-1-ol, Liu *et al.* synthesized aliphatic polyester. CO may be converted to undec-10-ene-1-ol via thermal cracking and hydrogenation[48].

Sulfated castor oil

Sulfated CO, also known as turkey red oil, is a light yellow to dark brown liquid and has high whip ability and emulsifying power. Sulfated CO serves a variety

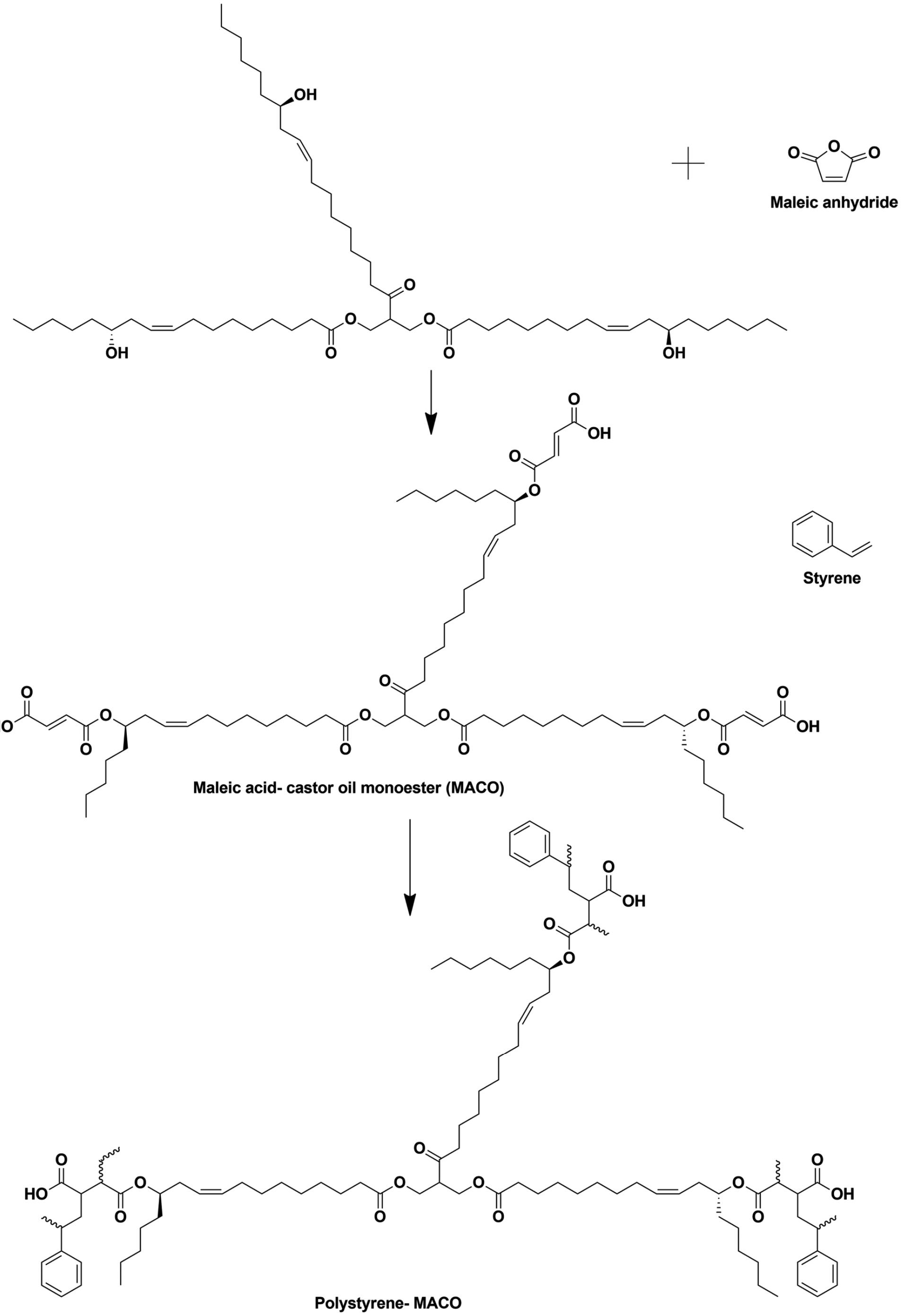

Fig. 3 — Polymerisation of castor oil.

of functions and is frequently utilized in industries such as paper production, leather, coating, and weaving. The technique includes the following detailed steps: CO is subjected to a sulphation process by adding a catalyst, dumping fuming sulfuric acid at a temperature between 20°C and 28° Celsius for one to two hours, continuing the reaction for three to five hours while maintaining the temperature between 28°C and 38° Celsius, and getting a CO sulphate solution (Fig. 4). The CO sulphate solution is then washed with saturated salt water. Turkey red oil is used as a synthetic detergent in bath oil recipes, fragrance or essential oils, shampoos, and agriculture as organic manure[49].

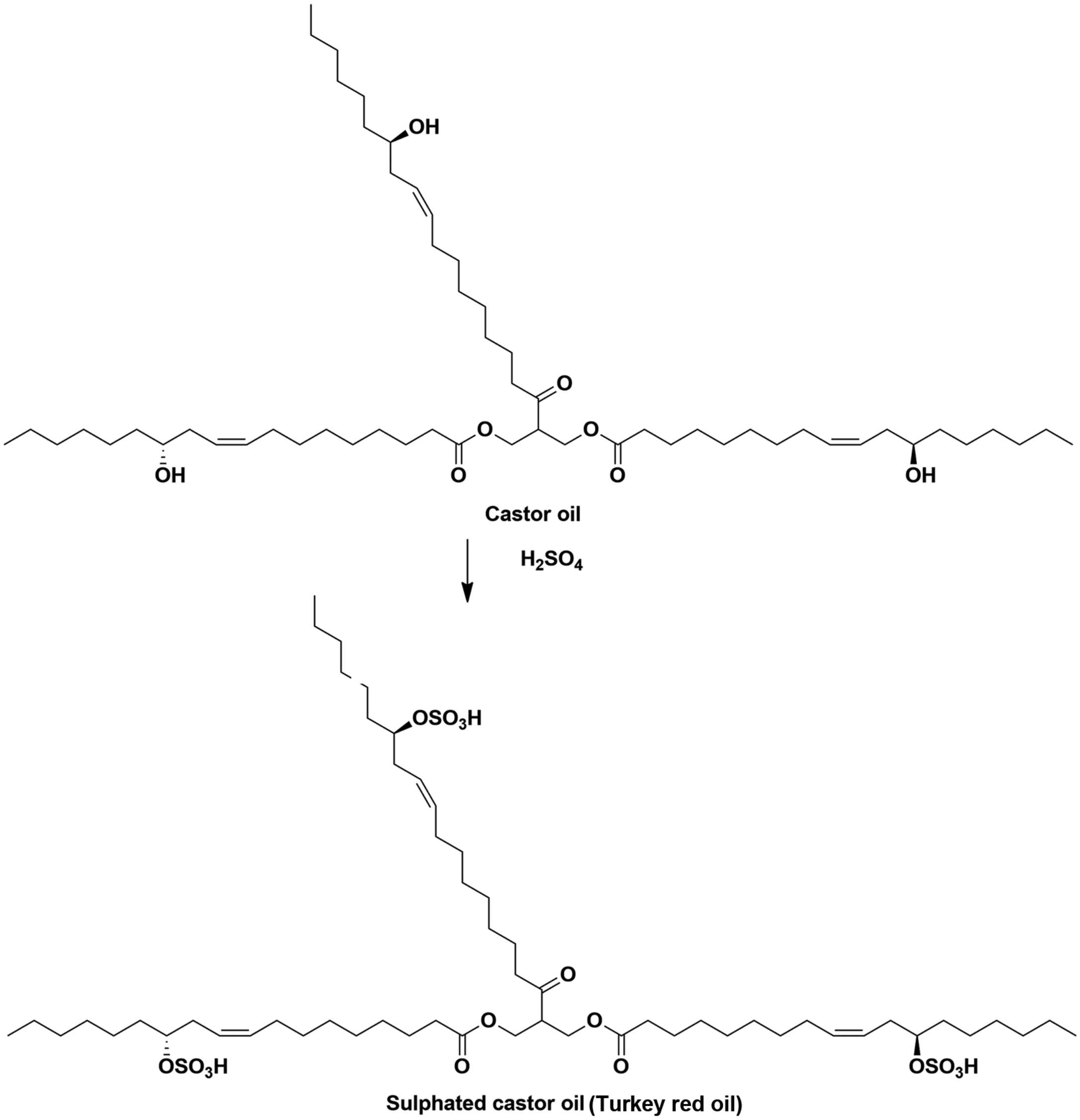

Fig. 4 — Sulfation of castor oil.

Hydrogenated castor oil

Castor wax, commonly referred to as hydrogenated CO, is a hardened vegetable wax created by the chemical process of hydrogenation from pure CO. In the presence of a nickel catalyst, hydrogen is added to pure CO to produce a waxy, extremely viscous, and more saturated end product (Fig. 5). It is a common component of many cosmetics, varnishes, and polishes. It has no odour whatsoever, unlike pure CO, which is supposed to have a mildly repulsive stench. Additionally, it is water-insoluble. The final product made from CO after hydrogenation is made up of brittle and hard flakes. Due to its vegetable origins, hydrogenated CO is regarded as an organic and vegan component[50].

Sebacic acid

Sebacic acid is a valuable ten-carbon aliphatic dicarboxylic acid derived from CO. To synthesise the ricinoleic acid methyl ester, which is the starting material for the production of sebacic acid, CO methyl esters are refined. The 12 oxo derivatives are created by oxidising the -OH group of methyl ricinoleate, and the trans 10,11 isomer is subsequently created by isomerising the cis 9,10 olefinic link. To synthesise dimethyl decanedioate, the isomerised molecule undergoes dihydroxylation, methylation, and oxidative cleavage. Finally, hydrolysis of the dimethyl decanedioate is performed to produce sebacic acid (Fig. 6). Chromatographic and spectrum analyses are used

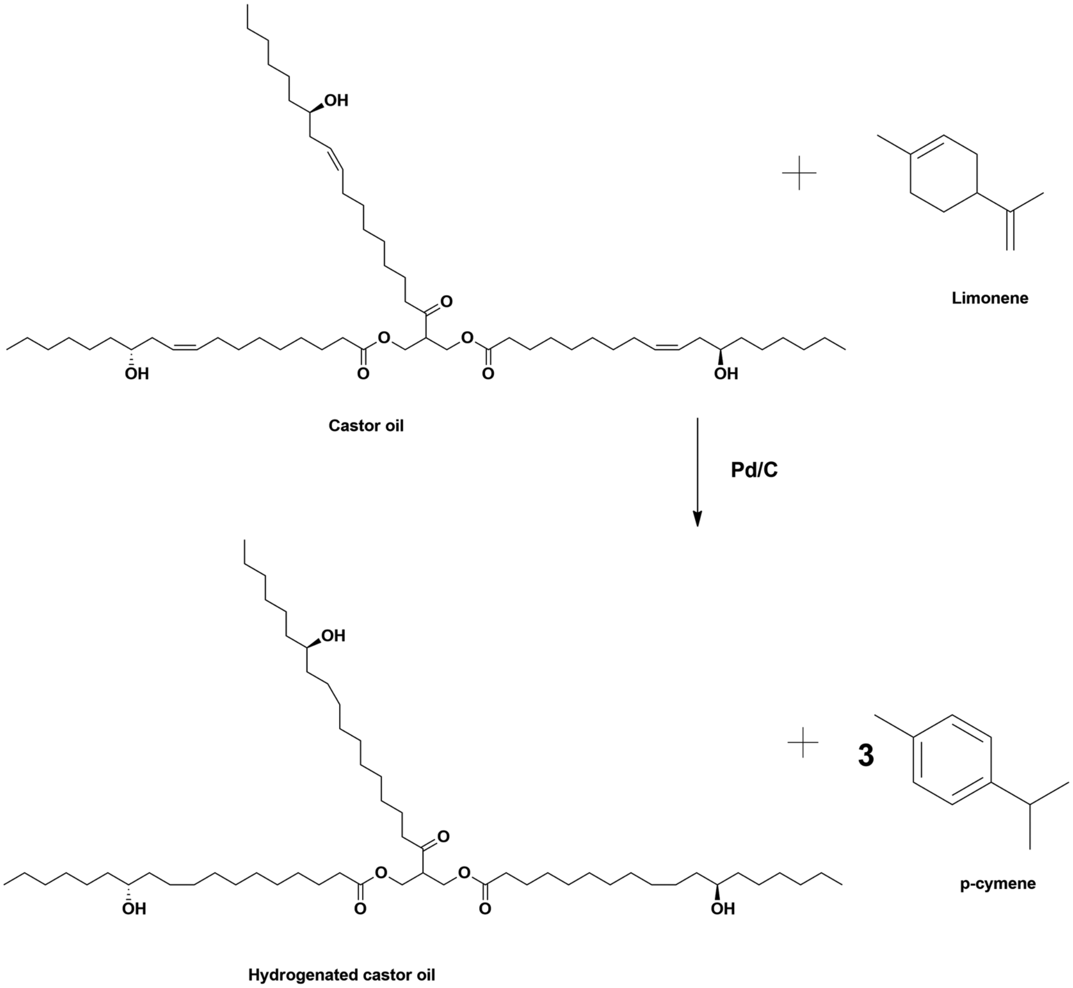

Fig. 5 — Hydrogenation of castor oil.

to purify and characterise the final product and intermediate components[51].

Sebacic acid is produced by alkali fusion using CO and its three derivatives: sodium ricinoleate, methyl ricinoleate, and RA. The catalyst, oleochemicals/ NaOH ratio, reaction duration, and temperature were among the tuned reaction parameters. The optimum catalytic performance was observed using a Pb_3O_4 (1%) solution, and 553 K was shown to be the ideal reaction temperature. The ideal oleochemicals/NaOH ratios for the CO's alkali fusion, sodium ricinoleate, methyl ricinoleate, and RA, were found to be 15:14, 15:12, 15:14, and 15:14, respectively. Additionally, CO's alkali fusion had an ideal reaction time of five hours, whereas three hours for its derivatives[52].

Ricinoleic acid (RA)

RA, a specifically hydroxylated, mono-unsaturated, eighteen-carbon aliphatic monobasic acid with a terminal carboxyl (–COOH) group and a branch-out -OH group with an asymmetrical twelfth carbon, makes up 90% of the total fatty acid in CO. CO is hydrolysed to produce RA, which is typically done in a basic environment.

RA is produced commercially by hydrolysed CO being saponified or fractionally distilled (Fig. 7). RA was isolated by many researchers using CO[53]. Some researchers utilised lipase, which was obtained from pulverised oat seeds and served as a catalyst to produce RA from CO. Hydrolysis was used to try to produce RA selectively[54].

12-hydroxy stearic acid (12-HSA)

CO naturally contains a significant amount of RA, which is hydrogenated to produce 12-HAS (Fig. 8). The ability of 12-HSA to rearrange itself generally depends on the presence, position along with the enantiomeric purity of the -OH group throughout the

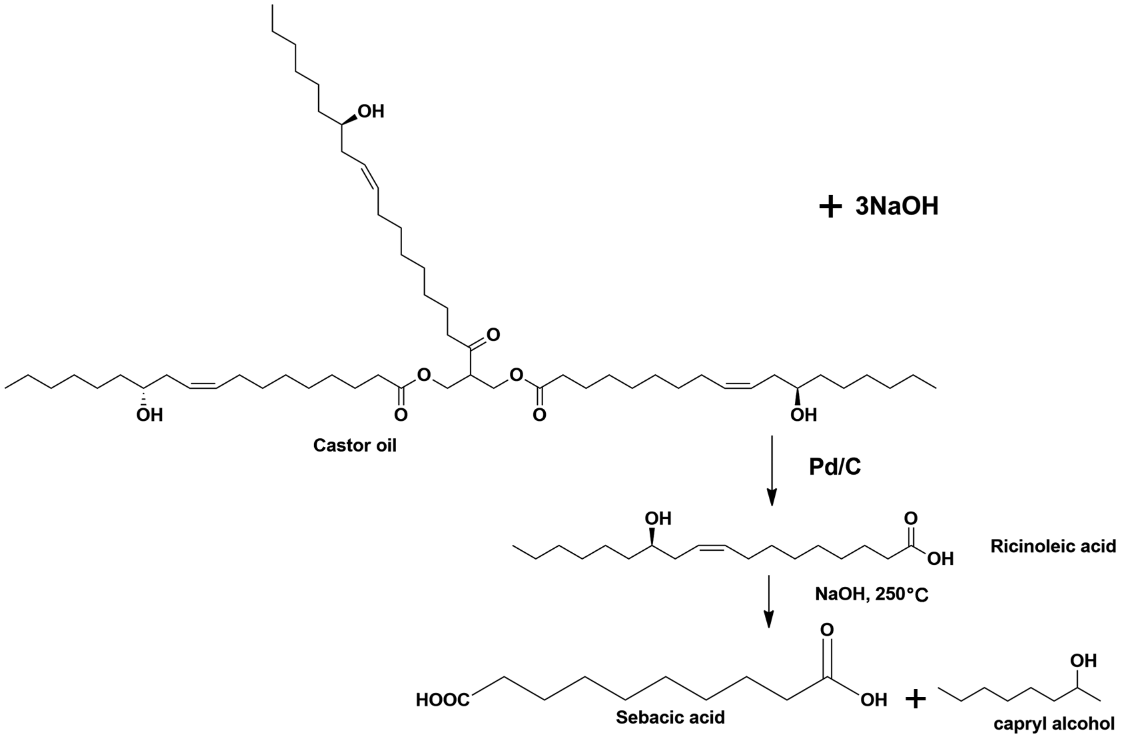

Fig. 6 — Production of sebacic acid.

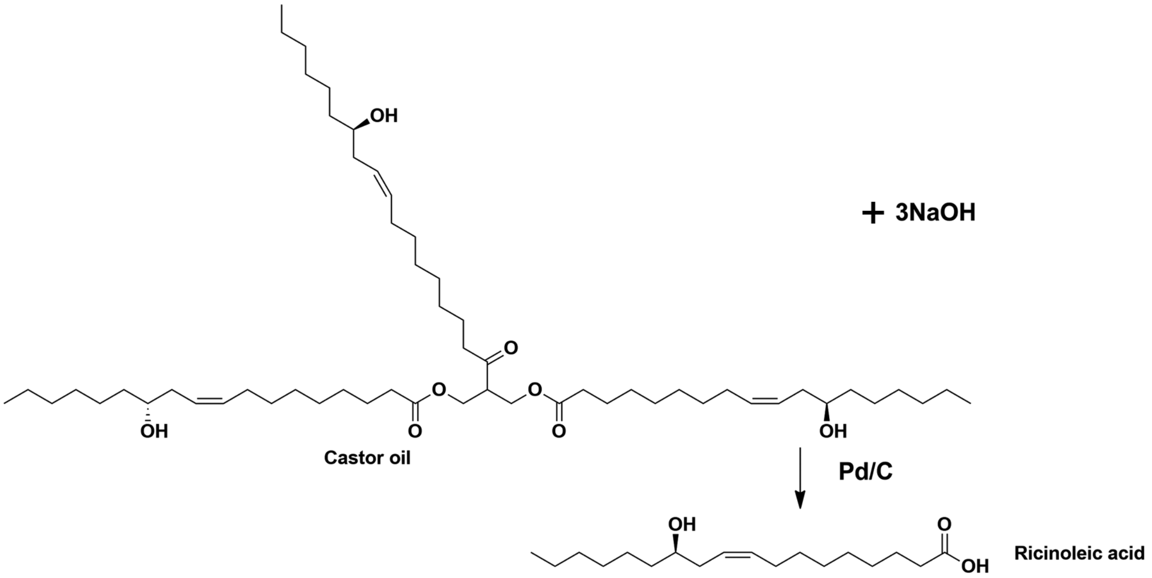

Fig. 7 — Hydroxylation of castor oil.

fatty acid structure. The -OH group's polarity and location allow for additional interaction an option, which contributes to its outstanding ability to self-assemble into ribbons, tubes, and fibres in a range of solvents. When 12-HSA self-assembles, it crystallises into high aspect ratio fibrillar structures as a result of noncovalent interactions between molecules that create three-dimensional networks (also known as self-assembled fibrillar networks), self-spanning in both hydrophilic and lipophilic solvents. Here, the focus is on 12-HSA supramolecular assemblies' new uses (such as drug delivery devices, gelled complex fluids, and responsive aqueous foams) in grease manufacture and plastics lubrication[55].

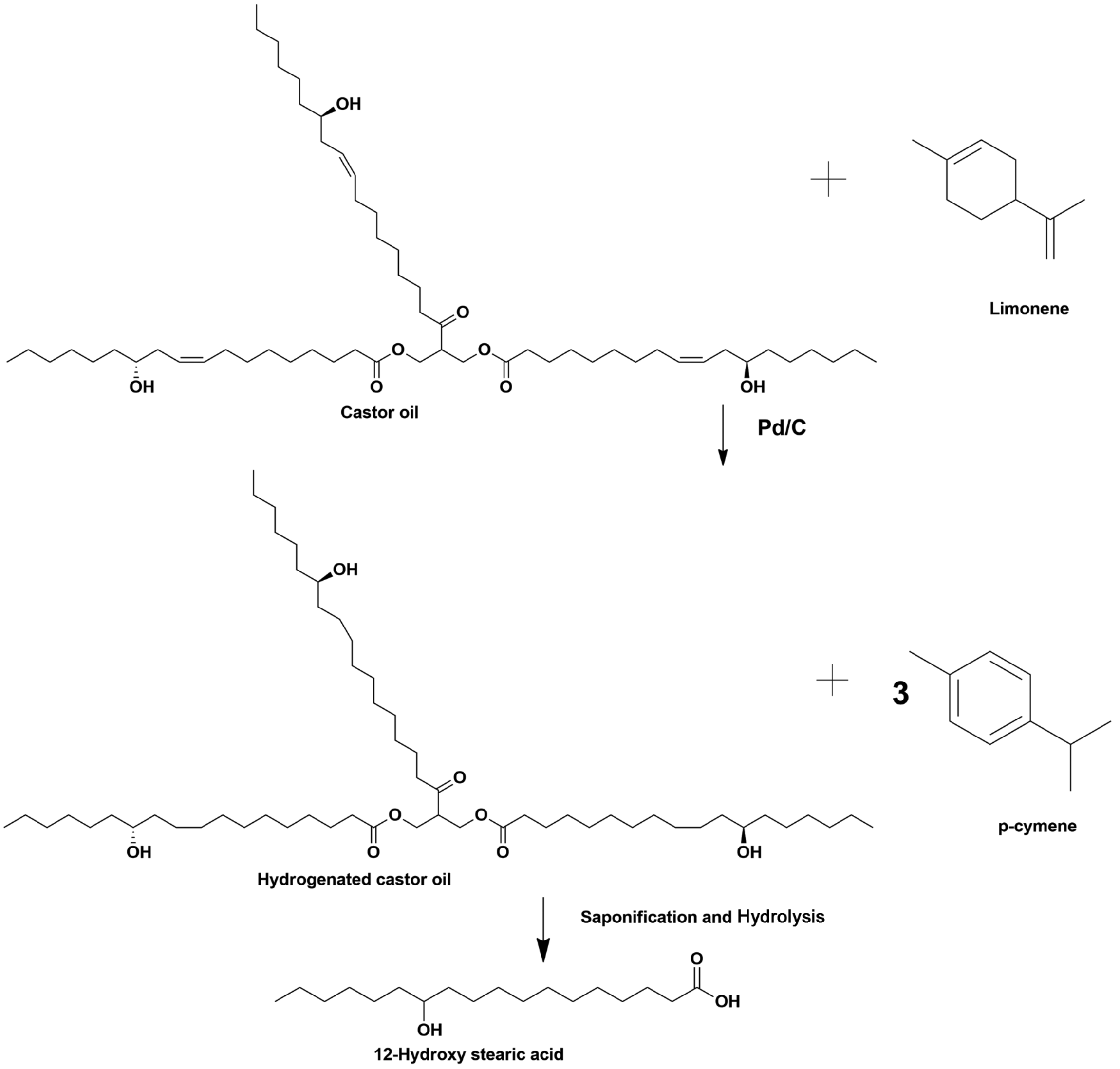

Fig. 8 — Hydrogenation of castor oil.

Dehydrated castor oil

The most well-known and often utilized of all the oils referred to as "synthetic" drying oil is dehydrated CO (DCO). DCO gives protective coatings high flexibility, quick-drying, great colour retention, and water resistance. The study found the appropriate reaction parameters (concentration of catalyst, temperature, time period, and pressure) to produce DCO from raw CO. Atmospheric pressure reactions employing N2 flow as a sweeping gas were carried out using Start S and Roto Synth, two separate microwave synthesis units. Using 4% catalyst (w/w) at 250°C for a 20 minutes reaction (Fig. 9), the iodine value and hydroxyl value of DCO were reported to be 135.8 and 140, and 12.3 and 11.9, respectively, at atmospheric and reduced pressure (500 mbar)[56].

Undecylenic acid

Heptaldehyde and undecylenic acid were produced by pyrolysing CO at 700°C at low pressure. It is the chemical breakdown of organic compounds that occurs when they are heated without the presence of oxygen or any other reagents other than steam. Heptaldehyde can be further hydrogenated to produce alcohol (Fig. 10), which is then used as a plasticiser. Methyl Undecylenate can also be used for hydrolysis. Undecylenic Acid is produced by hydrolysing methyl undecylenate[57]. As an antifungal medication, undecylenic acid has a lengthy history. Its use helps to cure a variety of fungal infections. In addition to serving as a biocide in soaps and deodorants, undecylenic acid may be utilised as a surfactant in hair lotions. It serves as the foundational component for Nylon 11[58-61].

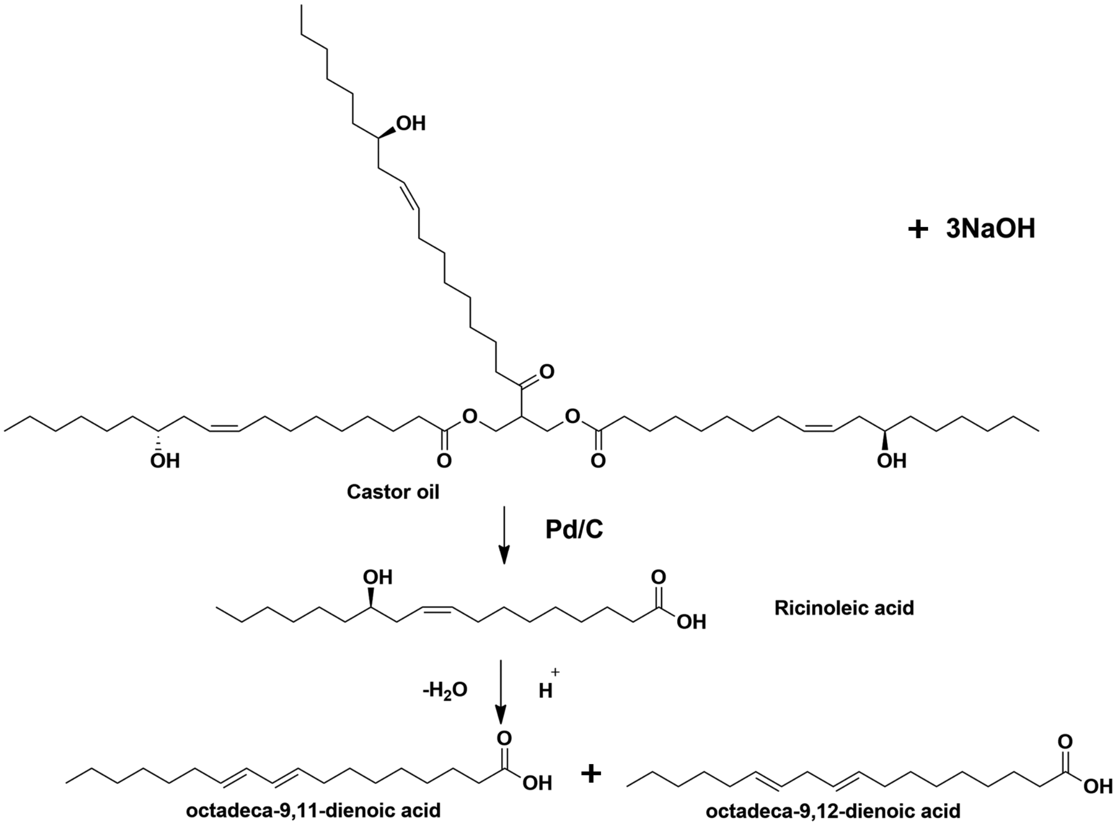

Fig. 9 — Dehydration of castor oil.

Acetoxy-epoxy derivatives

Pyridine and acetic anhydride can be used to acetylate substances that contain –OH groups and unsaturation, such as CO or its derivatives. Under non-acidic environments, the former can be epoxidised with the right chemicals, such as anhydrous peracids (Fig. 11)[62]. Because of the presence of epoxy groups and acetoxy groups, the products made from PVC resins may be predicted to display both a stabilising function and a plasticising function. Several studies have been done on this approach.

A number of chemicals with different epoxy-acetoxy ratios have been created by epoxidising CO and then acetylating the resulting compounds. CO may be used alone or in combination with different amounts of linseed oil[63]. The morpholide esters of cyanoethylated RA have demonstrated strong plasticising properties at the Southern Regional Research Laboratory (SRRL) in New Orleans[64] (Table 3).

Uses of castor oil

Laxative

Although CO is well recognized for being a potent laxative, the medical uses of oil are minimal (less than 1%). This oil is well-suited for a variety of physicochemical and physiological activities because of the higher content (%) of RA, which is close to the double bond[72]. Due to RA's action in the colon, CO is frequently employed in a variety of bioassays that assess the anti-diarrheal effects of compounds in lab animals. Rats are frequently given CO orally to cause diarrhoea[73-75]. With the use of this test, a quick and effective approach for preliminary screening of different phytochemicals for possible candidates for drugs that are similar to drugs derived from natural sources.

CO is also employed as a means of medication administered in contemporary medicine. Kolliphor EL, also called Cremophor EL, i.e. when thirty-five moles of ethylene oxide is combined with one mole of CO, the result is a combination known as polyethoxylated CO (CAS No. 61791-12-6), is a registered manufactured good of BASF Corp[76]. These goods are frequently used in pharmaceuticals as additives or excipients and are also employed to create stable emulsions of non-polar substances in a variety of aqueous environments. Additionally, the anti-cancer medications docetaxel and paclitaxel are

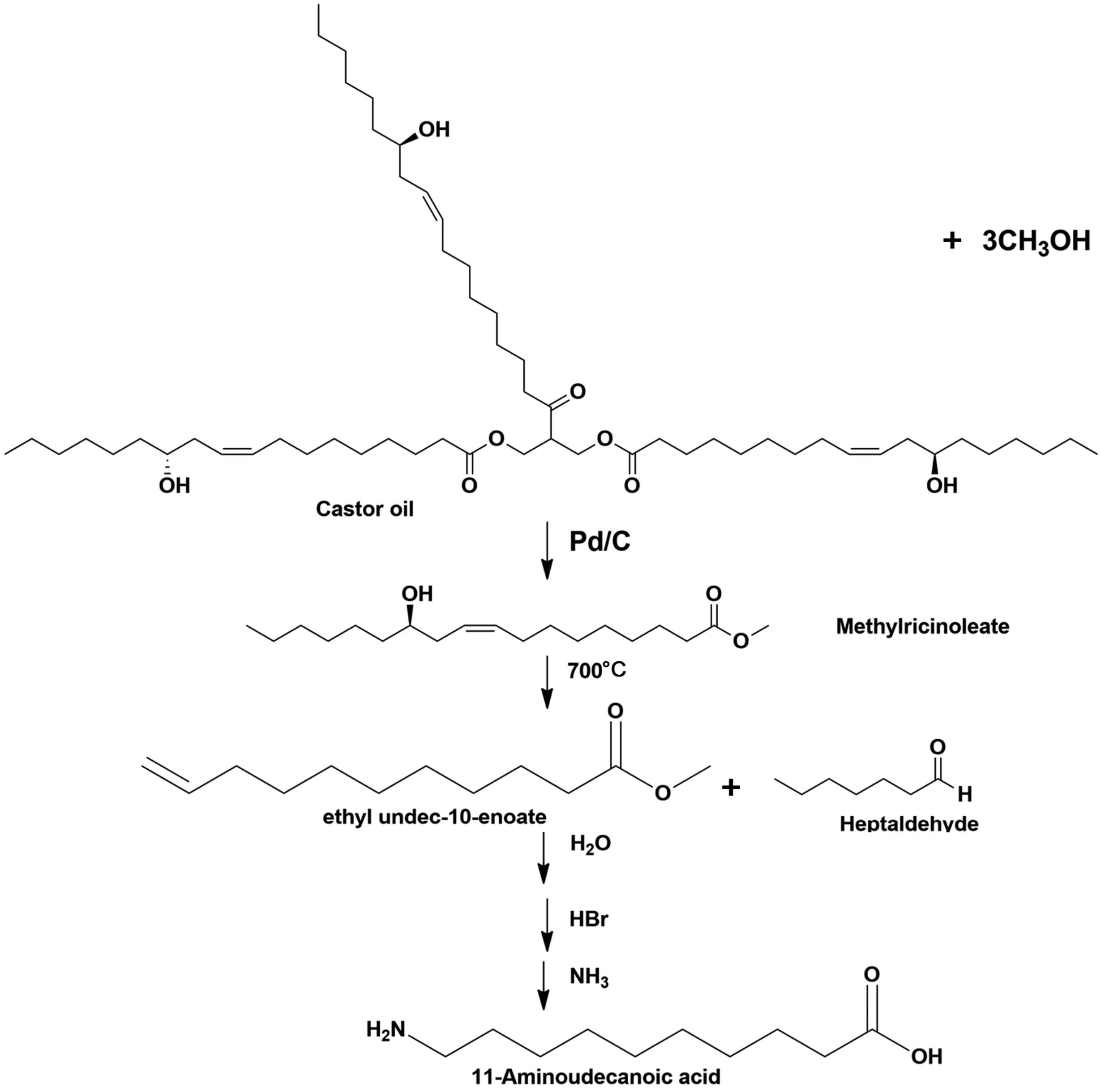

Fig. 10 — Pyrolysis of castor oil.

two examples of extremely nonpolar medicines that are frequently delivered using it as a drug delivery system[77].

Artificial leather

High-quality polish can be formulated using castor wax- a synthetic wax obtained from the hydrogenation of its oil with benzene as a solvent and carbon black as pigment or dye. This gives a polish with good penetration and thus provides protection to the polished leather. Good quality leather polish can be formulated at wax–to–solvent ratios greater than unity- using castor wax and benzene as wax and solvent resp. With a wax-to-solvent ratio of two, a leather polish of the best quality is produced[78,79].

Synthetic drying oils

Tung and linseed oil are called "drying oils" due to their involvement in the oxidation process. Linseed oil has a significant amount of glyceride of linolenic acid with a triple bond. Unsaturated fats are present in both tung oil and linseed; however, tung oils's double bonds are conjugated, whereas linseed's are not. Due to the fact that an equivalent amount of isolated

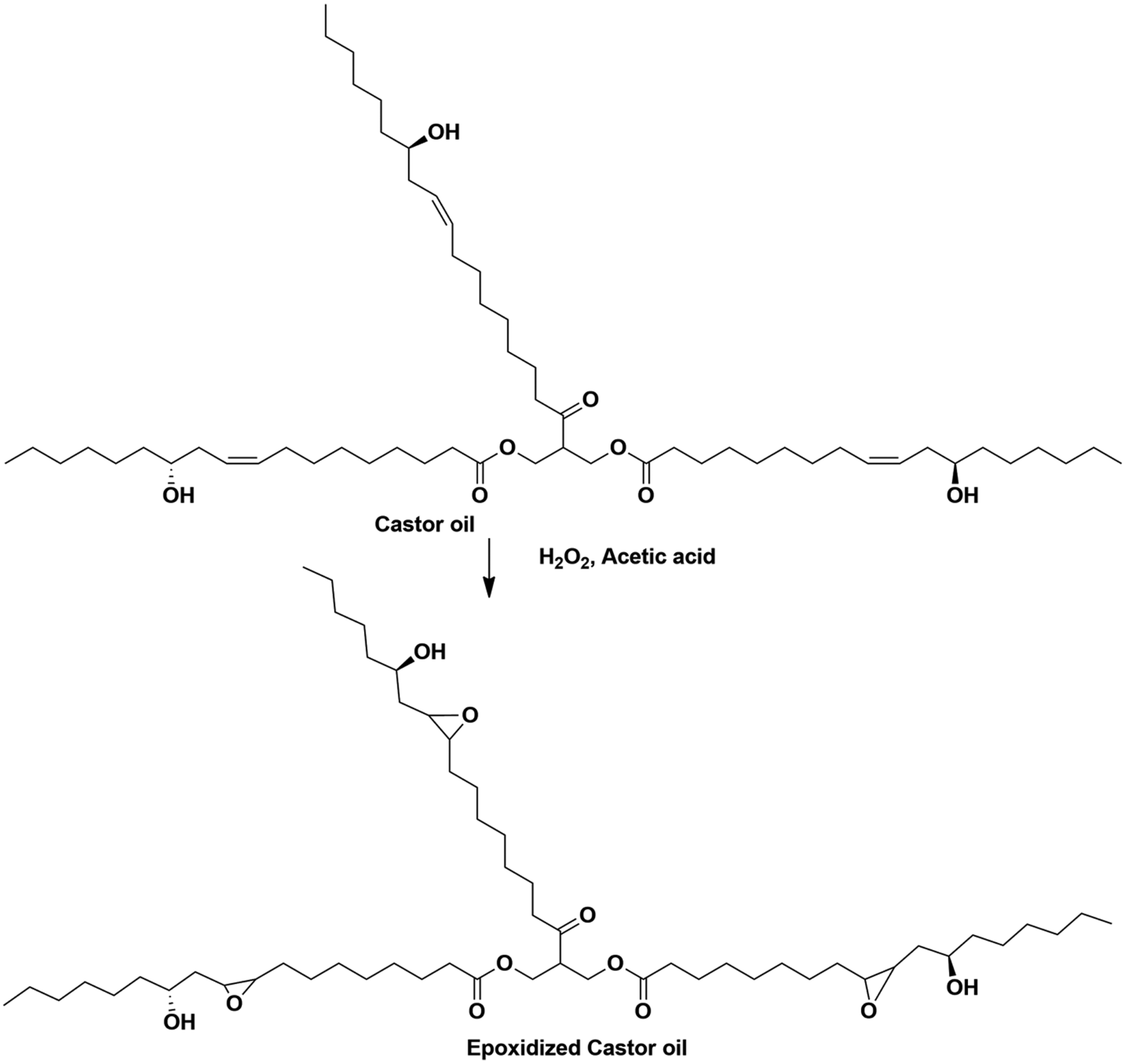

Fig. 11 — Epoxidation of castor oil.

double bonds are less reactive than those that are conjugated, therefore tung oil dries significantly more quickly than linseed oil. CO cannot mix with ambient oxygen to produce a paint coat, as it only has one double and weak drying capabilities. According to the studies on the structure of RA, the development of a second olefinic bond would result from the elimination of the -OH group as water. This dehydration is easily accomplished by heating the oil in the presence of catalysts for splitting water, which is often a moderately acidic compound like sodium acid sulfate[79]. Dehydration may and can happen on either side of the carbon-carrying –OH group; therefore, not all double bonds in the material, known as "dehydrated CO" appear to be conjugated. It is fascinating to notice that linseed oil takes longer to dry a paint coat than dehydrated CO, which includes some conjugated double bonds, but slower than tung oil, which includes the majority of conjugated bonds. Nowadays, most of the drying oils are imported, in which about 95% of the tung oil is used by the paints and varnish industry, i.e. 85-125 million pounds is imported from China[80].

Lubricants

Prior to the development of mineral oils, fatty oils were almost exclusively used to lubricate mechanical moving parts. For engines that run at high speeds for

Table 3 — Chemical derivatives of castor

S. No.	Name of Castor Derivative	Type of Reaction	Reactant	Reagent/ Catalyst	Solvent	Application	Ref
1	Polymerized CO	Epoxidation and Polymerization	CO	Methacryloyl chloride, Styrene	Acrylic acid, Meth-acrylic acid,	Industrial replacement for Styrene	65
2	Turkey Red Oil	Sulfation	CO	Sulphuric acid + ammonia	---	Corrosion inhibitor	49
3	Hydrogenated CO	Hydrogenation		Limonene + Pd/C		Cosmetics, Polishes	66
4	Sebacic acid	Hydrogenation + Alkali fusion	CO	Pb$_3$O$_4$ 1% solution	---	In nylon synthesis	67
5	Ricinoleic Acid	Hydrolysis	CO	Pd/C, Sodium hydroxide	Glycerol		68
6	12-Hydroxy Stearic acid	Hydrogenation	CO	Limonene+Pd/C	---	Lubricant, Gelled-complex fluids, Grease Manufacture	69
7	Dehydrated CO	Dehydration	CO	NaOH, Pd/C, H2O	----		70
8	Undecylenic acid	Pyrolysis	CO	Pd/C, CH$_3$OH, 700°C		Antifungal, Surfactant	57
9	Acetoxy-epoxy derivative	Epoxidation and Acetylation	CO	Acetic anhydride, Pyridine	----	Plasticizer	71

limited intervals of time, CO was discovered to offer very smooth lubrication. Generally, it was noticed that these provided performance that was pretty acceptable given the basic needs of the period. For a brief period, early racing and aircraft engines ran smoothly with CO as long as the piston temperatures were kept at a reasonable level[81].

However, it was discovered that using CO in the same engine indefinitely caused the fatty oil to break down, resulting in the production of a sticky, resinous substance that makes the engine worthless. This problem became more urgent as faster engines with higher operating temperatures were developed, but it was resolved while CO was rendered obsolete by the advancement of mineral lubricants used for increased productivity motors. However, CO is still used for engine lubrication despite the widespread use of petroleum-based oils. Before switching to mineral oil, new engines are treated with CO, and it has been observed that the oiliness of CO is known to continue for a specific time period following the switchover[82]. According to contemporary lubrication theory, fatty acid esters (polar molecules) are efficient lubricants because their functional groups permit surface orientation, resulting in the production of a tenacious layer that concurrently lowers friction. Due to the presence of the –OH group, CO is even more polar than other types of fatty oils, and as a result, one might anticipate that it would have significantly much higher oiliness (ability to decrease friction). The majority of mineral oils are composed of non-polar hydrocarbon molecules, making them less oily than fatty oils and especially less oily than castor. Although their decomposition is not as objectionable, mineral oils are stable. It is conceivable that mineral oil and CO could be combined in a way that produces a safe lubricant with much higher oiliness[83]. Unfortunately, the –OH group that gives CO its improved oiliness prevent it from being soluble in mineral oils. Chemists have put much effort into achieving miscibility, but the outcomes so far have not been all that great. The use of the emulsifying agent triethanolamine is a different technique that is allegedly being produced commercially in Brazil[84]. Although heating and air blowing increase the material's mineral oil solubility, the resulting mixture is reportedly unsatisfactory. This is possible because some -OH groups that cause oiliness are removed as water during heating. Without a doubt, dehydration on the hot metal surfaces of the motor plays a role in the formation of resinous materials from CO when it is used as a lubricant for an extended period of time[85].

Wetting agents

These agents are typically prepared by combining two groups-one water-soluble (sulfate) and another oil-soluble (long paraffin chain) into a single molecule. CO is an ideal starting material for making such compounds since it is simple to alter the –OH group connecting to the fatty acid paraffin chain to create water-soluble groups. CO has traditionally been used to create "turkey-red oil material," so named because it works as a penetrating and wetting agent when combined with red alizarin dye. CO is subjected to a strong sulfuric acid treatment before being neutralised with alkali to create turkey-red oil. The resulting product allows dyestuffs to penetrate fabric fibres and stay more tenaciously[86].

In order to create an alkyl sulfuric acid, it is likely that the -OH group will be esterified, and a sulfuric acid molecule will be added over the olefinic double bond[87]. The amount of sulfate group present determines the solubility in aqueous solvents, which is regulated by the circumstances surrounding the sulfation. Turkey red oil is still commonly utilised by dyers despite the market being invaded by several recently created special purposes wetting agents[88].

Fuel and biodiesel

Non-edible crops like Castors are considered promising crops because of their high yield and annual seed production, ability to grow in marginal soil, and semi-arid climate. Few studies have been done on the characteristics of castor fuel, either in its pure form or when combined with diesel fuel, partly due to the unusually high amount of RA. When combined with diesel fuel, CO methyl ester can be utilised as a substitute raw material for biodiesel according to research shown by Berman *et al.*, The high levels of RA in the oil, which have a direct impact on the kinematic viscosity and distillation temperature of biodiesel, limit the amount of oil that may be blended to a maximum of 10%[89]. Shojaeefard *et al.* conducted a study to examine how Co biodiesel blends affected the efficiency and emission of diesel engines[90]. They found that an optimised biodiesel-to-diesel ratio contained 15% CO. The results demonstrated that lower biodiesel blends offer acceptable fuel for engine performance. Addition of potassium hydroxide as a catalyst for trans-esterification, Panwar *et al.* produced castor methyl ester[91]. In a four-stroke, single-cylinder diesel engine with a variable compression ratio, they then put this methyl ester to the test. The lower biodiesel blends were found to increase break thermal efficiency and reduce fuel consumption. Furthermore, the temperature of the exhaust gases increased along with the biodiesel concentration. Their study's conclusions showed that using biodiesel made from CO as a diesel replacement in compression ignition engines is successful. Several typical catalytic systems were used to study the trans-esterification reactions of CO with methanol and ethanol as trans-esterification agents[92]. Despite the positive outcomes of this research, there is still a considerable hurdle in some nations, such as Brazil, to the use of CO as a technically efficient and effective biodiesel fuel. To aid small producers in the semi-arid portion of the country, the Brazilian government pushed castor as a biodiesel feedstock[93,94]. The Brazilian biodiesel program has been in place for seven years, but relatively little CO has been used during that time. It was found that rather than being used to make biodiesel, the CO produced under this program was primarily sold to the chemical industry for higher prices[95]. CO's high price as an industrial oil has been a major deterrent to its use rather than its physical and chemical properties. CO is widely used in the chemical industry to produce products with extremely high value. This makes substituting this oil for diesel an expensive proposition. Although CO may be a direct substitute for ordinary diesel fuel, its high viscosity also restricts its utilization[96].

Polymer materials

Renewable monomers and polymers can be prepared using CO and its derivatives[97]. CO was used to synthesise vulcanised and urethane derivatives in one study by polymerising it and cross-linking it with sulfur or diisocyanates, respectively[98]. In a different study, polyurethane (PU) and epoxy were synthesised sequentially to create full-interpenetrating polymer networks (IPNs)[99]. The sequential method was used to prepare a variety of two components of IPN comprised of customised CO-based PU and polystyrene (PS)[100]. IPN can be defined as a particular class of polymers in which two polymers are combined, and one of them is synthesised or polymerised while the other is present as such[101,102]. Compared to traditional poly-blends, IPN formulations might be a useful method for synthesising a product with superior physico-mechanical qualities. One of the study fields for polymer blends that are estimated to have expanded the quickest during the previous two decades is IPN, also known as polymer alloys. CO polymer has also shown sealing qualities when used as a root-end filling agent. Creating an apical seal that stops bacterial diffusion into the periapical tissues and bacterial movement within the root canal system is the primary objective of this material[103]. In research, De Martins *et al.* evaluated the sealing ability of CO polymer, glass ionomer cement (GIC), and mineral trioxide aggregate (MTA) as root-end filling substances[104]. Popular bioactive materials known as GICs are bioactive and have a range of applications, including tooth restoration, sealing, bonding, lining and luting. On the other hand, Bismuth oxide, tricalcic alluminate, and tricalcic silicate are the main ingredients of the particular type of endodontic cement known as MTA[105]. The result of their investigation showed that when utilised as a root-end filling substance, CO polymer had a greater sealing performance than other polymers[106].

One of the most frequently used CO applications is the production of biodegradable polyesters (PEs)[107]. In the 1930s, Carothers created PEs as the first synthetic condensation polymers[108,109]. They are used in a variety of ways by the biomedical industry, including the production of elastomers and packaging materials. They are also known to be environmentally friendly and biodegradable. Despite being desirable biodegradable polymers, fatty acid scaffolds are constrained by their single function. Thus, the majority of fatty acids only contain one carboxylic acid group. The 12-hydroxy group, in addition to the terminal carboxylic acid, makes RA an example of a naturally occurring bi-functional fatty acid. This -OH group's presence adds functionality to the process of synthesising PEs or polyester-anhydrides (PE-Ahy). The hydrophobicity of the RA's chains impacts the physical and mechanical characteristics of the resulting PEs. By lowering the glass transition temperatures of the polyesters, these chains serve as plasticizers[110,111]. A variety of copolymers can be created by mixing CO with additional monomers. These copolymers can be fine-tuned to produce substances with a variety of characteristics that are employed in items like solid implants and locally injected hydrophobic gel[112].

Soaps, waxes, and greases

Some studies have shown the usage of CO in the manufacturing of soap[113,114]. CO is also used in waxes in some studies[115]. Dwivedi *et al.* used CO in all vegetable oil greases in one of their studies. Total vegetable oil greases are those that contain vegetable oil as both the lubricant and the gallant. CO was used in their study to create sodium and lithium greases using a simultaneous reaction scheme[116].

Fertilisers

Husks and meal are the two main byproducts produced during the production of CO. Approximately 1.10 tons of meals and 1.30 tons of husks are produced for every ton of CO. Castor meal and castor husk fertiliser combinations significantly accelerated plant development up to a dose of 4.5% (in volume) of meal, according to research by Lima *et al.*, A dose above 4.5%, however, resulted in a reduction in plant growth and even plant death. Because castor meal contains a lot of nitrogen and phosphorus, according to their research, it can be used as a good organic fertilizer[117].

Coatings

Castor oil is also used in paint and coatings. Non-conjugated oil-maleic anhydride adducts are capable of dehydrating CO in a way that is efficient enough to produce beneficial paint or furniture oil[118]. Trevino *et al.* investigated the usage of CO as a coating material by transforming the -OH functions of CO into keto-esters with the aid of t-butyl acetoacetate. It is known that the reaction will occur quickly and with a high yield under favourable conditions. The results demonstrated that the films have good glosses and flexibility[119]. In an investigation, a highly branched macromolecule, hyper-branched polyurethanes (HBPUs) based on CO, were used to create advanced surface coating agent[120]. The HBP showed superior performance as surface coating agents with the monoglyceride-based HBPU and had greater tensile strength than direct oil-based coatings. With thermal stability for both polymers of more than 250°C, both HBPUs have acceptable dielectric properties. CO is also used as a coating agent in ceramer coatings. CO that had been epoxidised was combined with tetraethoxysilane to create ceramic coatings[121]. Allauddin *et al.* most recently developed high-performance hybrid coatings by synthesising CO with hydrolysable -Si-OCH$_3$ groups, a technique also used to create PU/urea-silica hybrid coatings[122].

Anti-fertility activity

A research looked at the phytochemical assays for steroids and alkaloids in *R. communis* seed extract. The outcome was favourable. Since methanol extract from *R. communis* seeds also indicated the presence of steroids, which are sex hormones, these substances have anti-fertility effects[123].

Anti-asthmatic

Because of the presence of saponins and flavonoids, which are phytochemicals that fight allergies and stabilise mast cells, an ethanolic extract of the root of the castor plant is thought to be helpful in treating asthma. While flavonoids have the ability to relax smooth muscle, saponin has the ability to stabilise mast cells. Additionally, they are in charge of the bronchodilator effect[123].

Anti-diabetic

The anti-diabetic potential of *R.* communis root extract (RCRE) was assessed. The diabetic rats received 500 mg/kg b.w. of RCRE for 20 days in order to achieve this goal. The outcome showed beneficial effects on liver and kidney functions in addition to total lipid profile and fasting blood glucose. Out of all the evaluated reactions, only one (R-18) showed significant antihyperglycemic activity. *R. communis* can thus be a useful phytomedicine for diabetes[124].

Anti-amoebic

The antiamoebic properties of several *R. communis* root and stem extracts were investigated. The root's ethanol/water (1:1) extract in broth culture, at 125 mcg/mL, and the stem's analogous extract were both effective against *Entamoeba histolytica*[125].

Anti-cancer

The current study examined the *in vitro* anti-cancer properties of *R. communis's* ethanolic extract against seven human cancer cell lines. The seven cell lines included the following: OVCAR-5 for the cervix, PC-3 for the prostate, T-47D for the breast, Hep-2 for the liver, and Colon HT-29, SW-20, SiHa for the colon. The sulforhodamine B (SRB) assay was utilised to evaluate the cytotoxic impact of the test material on all cell lines at a dose of 100 µg/mL. The stem portion of the *Ricinus communis* seed had the highest activity (47%), whereas the ethanolic extract of the seed showed 41% action against Colon 502713[126].

Toxicity Profile

As a result of Still Mark's 1988 experimentation with the bean extract on red blood cells, one of the primary harmful proteins is "ricin." When ingested whole, seeds travel through the digestive system without causing any damage. However, the ricin poisonous substance will enter the intestines if it ruptures or is crushed and then consumed. Children are more susceptible than adults to fluid loss from diarrhoea and vomiting, and they can quickly become critically dehydrated and pass away. It is stated that one seed can kill a kid. Perhaps just one milligram of ricin can kill an adult. Within a few hours of consumption, the main signs and symptoms of human poisoning include vomiting, diarrhoea, and occasionally bleeding abdominal pain. A reduction in urine production and a drop in blood pressure happen after severe dehydration that lasts for many days[127].

Conclusion

The stem, seeds and leaves of the castor plant can be utilised effectively to create goods with added value. Since ancient times, castor seed oil has been used in numerous industrial and medical fields; more recently, CO has been used effectively as a bio-surfactant, bio-lubricant, and bio-diesel. Despite being a rich source of starch, protein, and lignocellulose biomass, de-oiled castor seed cake is inappropriate for use as feed because it contains highly poisonous ricin. Castor stems and leaves make excellent biomass sources. According to studies, up to 90% of the castor plant's lignocellulose biomass may be transformed into fermentable sugars, which can produce ethanol or biogas. It is necessary to integrate a variety of reactions, using separation techniques and unit activities to produce fuels, feed components, a comprehensive set of products, and oleo chemicals. This requires the development of an environmentally friendly, coordinated approach. It is a significant problem that the production of biodiesel and oleo chemical feedstock results in the production of a significant amount of glycerol (as a byproduct). Toxicology is the other major issue that needs to be addressed with the residual meal. These problems can be solved by employing the proper methods for full utilisation of castor plants.

Conflict of interest

The authors declare that there is no conflict of interest.

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