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A Review of Simmondsia chinensis (Jojoba) "The Desert Gold": A Multipurpose Oil Seed Crop for Industrial Uses

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Abstract:
Simmondsia chinensis , a multipurpose, drought resistant, perennial plant belonging to Simmondsiaceae family has started to gain a lot of importance because of unusual oil which is actually a liquid wax i.e., an ester of long chain fatty acids and alcohols. Jojoba was introduced to India near the year 1965 and since then it has been a major source of income for both local farmers (having cultivations in locations like Sriganganagar, Sikar, Jhunjhunu, Churu and Jodhpur) and those who are working in jojoba oil trade. Jojoba oil has many usages depending on the site where the modification is being done. Virtually no traces of glycerine makes it a very unique plant based oil along with the fact that it can be modified via hydrogenation, sulfurization, halogenation, sulfurhalogenation, phosphosulfurization, ozonization, hydrolysis, amidation and many other techniques. With uses in industries like cosmetic, pharmaceutical, lubricant and petrochemicals, the importance of jojoba oil in the market is high. Before exploiting any plant for industrial application, it is imperative to have complete information about its biology, chemistry and all other applications so that potential of plant could be utilized maximally. Overall this paper introduces the shrub in its botanical totality, informs about its growth requirements and its local distribution in India. The purpose of this paper is to review the available propagation techniques, inform about its oil and seed meal processing and give detailed physico-chemical description of jojoba oil and cake. Moreover it also informs about the importance of jojoba oil and its applications.
Key Words: Jojoba oil, *Simmondsia chinensis* , Simmondsin

INTRODUCTION

Amongst the most unique creations by nature in the plant kingdom is a dioecious shrub with the botanical name *Simmondsia chinensis* . Being native to South-western North America and known by various local names like gray box bush, wild hazel, goat nut, pignut, coffeeberry, deer nut and quinine nut, this shrub is best known by the name of jojoba (pronounced *ho-ho-ba*) [1]. Positioned in the order Caryophyllales, *S. chinensis* is the only species of Simmondsiaceae family. In its native country, it inhabits an area of almost 260,000 Km Sq (100,000 sq mi) (between Lat 25° - 31° North and Long 109° - 117° West).

Documentation and citation of jojoba in literature date back to early 1700s. According to Rawles, the first citation of jojoba in literature was in the year 1701 [2]. Padre Luis Verlarde, while travelling to New Mexico, first documented the medicinal uses of jojoba [3] and its use as food, oil and in medicine (for diseases like cancer, kidney disorders, stomach aches and also for easing childbirth and tending wounds) by the Indians of Baja California was first reported by Italian Jesuit Francisco J. Clavijero in 1789 in his "Storia della California" [3], [4].

For the analytical purposes, seed oil of jojoba was first extracted via modern methods in 1929. In 1933 Green and Foster of University of Arizona conducted its detailed chemical analysis and found that seed oil of jojoba was in fact liquid wax (esters of long-chain acids and alcohols rather than glyceride fats) which is why jojoba has a unique place in plant kingdom [3]. In this respect, jojoba oil is also like sperm whale oil thus has many important uses including usage as lubricant. Because of this property of the jojoba oil, south-western United States and northern Mexico started experimental planting of jojoba but mostly for the purpose of research. It was only after the WW-II that commercial farming of jojoba was seriously explored and by 1982, USA, South America, Mexico and Israel started commercial harvesting [5].

In India, jojoba was first introduced around the year 1965 but it was not until the 1980s when the fascination towards the plant grew [5] Various research institutes started conducting experiments to study adaptability, production and utilization of agro-technology related to this shrub and profitable yields resulted in naming the shrub as "the Desert Gold" [6]. The purpose of this review is to provide information about its biology, chemistry, various industrial uses, and the benefits on the rural and urban economy.

BOTANICAL DESCRIPTION

Jojoba is an evergreen/perennial shrub having a multi-stemmed woody growth and a natural life span of up to 200 years [7]. It can reach up to three meters in height and can vary from being almost prostrate with lateral branches to being an upright plant [4],[8]. Mature plants [**Error! Reference source not found.**(A)] have a hard and heavy stems which are yellowish in colour and have no distinctive smell.

Depending on the moisture and availability of shade, lifespan of leaves vary from two or three seasons where they fall after developing abscission layer. They are lanceolate in shape and deep green in colour. Leaf size can vary from being 2.5-5.0 cm long and 1.5-2.5 cm wide [8]. Leaf blades of jojoba are stiff, thick, leathery and erect but can be easily detached when bent along the twig. Petioles are less than half a centimetre in length. Leaves also have a waxy coating which helps in reduction of transpiration [9].

Figure 1: *Simmondsia chinensis* (Jojoba); Plantation, Flowers, Seeds and Oil.

Being dioecious, male and female plants grow separately and are wind pollinated. Staminate flowers borne in the leaf axils are found in clusters, small in size (about 0.4 cm) and are yellow in colour [**Error! Reference source not found.**(B)]. On the other hand pistillate flowers grow solitary and are pale green to colourless without nectaries or scent glands [**Error! Reference source not found.**(C)]. They can be "sessile or with short peduncles, sepals 5, unequal, increasing in size as the fruit develops, styles 3, ovary superior, 3-celled, becoming 1-celled by abortion. They are borne in the axils of the leaves and the forks of the twigs concomitant with new shoot growth" [8], [9].

It has a well-developed taproot system which can grow to a depth of 30 to 45 cm by the time the shoot starts to penetrate the soil. In a mature plant, this system can grow up to 15-25 meters below ground showing numerous tap roots having frequent forking below the crown [3]. At the depth of around 0.6 to 1.0 meter small hairy rootlets have also been observed. This substantial network of parallel laterals and secondary roots allows jojoba to absorb moisture and minerals from a large area of soil allowing it to survive harsh growth conditions [3], [10].

Seeds of jojoba [**Error! Reference source not found.**(D & E)] are acorn shaped with small pointed apex and flat base with indentation. They are 12-18 mm long and are roughly triangular in shape having a breadth of 6-12 mm [9]. Weight of the seeds is generally accepted to be 1 kg for every 1600 seeds and they contain little or no endosperm, instead they are made up principally of undifferentiated cotyledons [3]. As long as the capsule remains green, seeds continue to draw nutrients from them and both seed and capsule matures together. Since the seeds do not go through the period of dormancy, they can be germinated soon after harvesting [7]. Germination of seeds requires a temperature range of 28-38 °C and best soil conditions are alkaline sandy media [8]. Oil content ranges from 44-59% and not much variation in the quality of oil is seen when seeds are taken from different geographic regions [11].

ECOLOGICAL REQUIREMENT, PROPAGATION TECHNIQUES AND PRODUCTION DISTRIBUTION:

Jojoba is gaining rapid popularity in many developing economies. Alongside USA, it is being cultivated in countries like Paraguay, Costa Rica, Mexico, Egypt, Chile, Kenya, Namibia, Peru, Israel, Jamaica, Brazil, Tanzania, Australia, Argentina Venezuela, and South Africa. [12]. A wide variety of soils are suitable for growing jojoba which includes gravel and rocky soil, soils having silt and clay below upper soil and soils that have acidic or basic pH (pH 5 - 8) [5]. Being a desert shrub, it is capable of growing in highly variable temperature conditions which ranges from 5-55 °C. Temperature settings of 25-30°C are most favourable for seed germination along with moist soil. Although ideal conditions for the growth require 450-650 mm annual rainfall, it is capable of surviving in 200-1200 mm rainfall regions. In high rainfall regions, the plant requires proper drainage. Fruiting starts from the fourth year and carries on for up to 150 years. Blooming of female flowers occur between December and January and seeds tends to mature between end of May and mid of June [5].

Propagation of jojoba can be done by different ways and plantations are established by methods like air layering, directly sowing seeds, grafting, using seedlings and saplings, planting cuttings or using tissue culture techniques. Sexual propagation of jojoba (direct seed sowing) is easy and seeds have been shown to be viable even after 11 years with 38% germination rate [9]. Although simple, this method has certain issues involved to it. Plants produced through this sexual propagation method are less productive, weak and disease prone. Also, when first grown as potted nursery stock, they do not transplant well [8]. With this technique, it is also difficult to analyse the sex as male plants outnumber the females [13] and large genetic heterogeneity affects yield, physiological characteristics, yearly bearing and growth uniformity [14], [15].

Asexual propagation techniques are much better to use as they provide with uniform results [16], [17] and allow for identification and use of individual plants with high yield and other advantageous attributes. Using vegetative propagation techniques one can achieve high and uniform yield, early fruiting, reduced post harvesting costs and development of desirable clonal varieties [18]. Jojoba saplings and seedling have different types of rooting systems; saplings develop more fibrous root system whereas seedlings tend to have deep tap root system. It is because of this difference saplings tend to be more sensitive to stressful conditions and transplantation from one location to another is risky [19]. A solution to this situation is to provide the sapling with well irrigated conditions [8] and to transfer them to fields 8 - 10 months after they were transferred to bags [20]. In general, younger than two years of saplings are considered suitable for transplantation and their survival rate is estimated to be around 75 to 95% [21]. **Error! Reference source not found.** -**Error! Reference source not found.** informs about three key propagation techniques, best months of their applications and use of selected growth hormones.

Table 1: Propagation by Air Layering

Rooting In	Treatment With	% Success	Months	Reference
Female	406.4 mg/l - IBA +3724 mg/l - NAA	---	---	[16]
Male	4064 mg/l - IBA +3724 mg/l - NAA	90%	---	[16]
Both	500 - 1000 mg/l - IBA	---	---	[20]
Ringed Shoots (ring of 2.5 cm after removing bark)	500 mg/l - IBA	---	Mid-January to mid-March and in mid-August	[69]
Both	6000 mg/l - IBA	68.10%	June to August	[70]

Table 2: Propagation by Grafting

Method	Procedure	% Success	Months	Special Notes	Reference
Splice or Whip Grafting	0.5 to 1.25 cm Scion of Mature Wood* with Greyish Brown Bark of 1 Or 2 Year Old Branches	---	Mid-February - Mid-April	*Poor Results with Immature Wood	[9]
Veneer Grafting and T-Budding	---	75 - 85% for Veneer Grafting	August - September -	August Grafting Better than September Grafting	[71]
Veneer Grafting and T-Budding	---	---	February - March -	Grafts Died Due to Hot Winds of April and May	[71]
---	Grafted Jojoba Males into Females	20%	---	Most Of The Grafted Males Produced Nuts in Two Years.	[72]

Table 3: Propagation by Cuttings

Type	Result	Location	Reference
Softwood Cuttings	Excellent Rooting	---	[73]
Hardwood Cuttings	Poor Rooting	---	[74]
4 Node Terminal and Middle Cuttings	Excellent Rooting	---	[19]
4-Node Basal Cuttings	Poor Rooting	---	[19]
Double-Eye Cuttings	More Rooting	---	[17]
Single-Eye Cuttings	Less Rooting	---	[17]
Rooting Ratio of Young Individual	Higher	---	[75]
Rooting Ratio of Mature Individuals	Lower	---	[75]
Spring Cuttings	longest roots	Israel	[19]
Winter Cuttings	Most Numerous Roots	Israel	[19]
End March - End August	Excellent Rooting	California	[9]
July or August	30 to 70%	Arizona	[9]
Rooting Rates @ 100 mg/l of			
IBA	82%	---	[21]
NAA	80%	---	[7]
IAA	76%	---	[7]

In 1990 USA had an area of around 16,000 hectare reserved for the cultivation of jojoba [22]. Between 1999 and 2001 Israel was world's third largest jojoba producing country and in 2007 the total world area under jojoba was 8,500 hectares which by the end of 2011 was producing around 5800 tons of jojoba seeds and 2700 tons of jojoba oil. In India, around 600-700 hectares of land area was under jojoba cultivation in 2011. Out of this, around 85-90% is in Rajasthan which is the largest jojoba growing state in India having cultivation in locations like Sriganganagar, Sikar, Jhunjhunu, Churu and Jodhpur [6], [12]. Gujarat and Maharashtra had approximately 100 and 50 hectare in 2011. Besides Rajasthan, other states with potential for jojoba cultivation include Punjab, Karnataka, Haryana, Orissa, Andhra Pradesh, Gujarat and Tamil Nadu [6], [23].

There are two major "time sensitive" issues with jojoba cultivation; the time period of 4 - 8 years that it requires to produce harvest and issues with collection of seeds as they fall on the ground making hand collection the only method of harvesting. For the former, the most followed suggestion is cultivation of annual crops like soybeans, watermelon, cotton, etc. between the rows so as to bare cost of up keeping of jojoba. For latter, hedge-row or orchard-type plantings along with pruning of bush to a specified shape tends to be useful. This gives easy access to suction-type mechanical harvester.

Disease and pathogen related issues include attack of termites during seedling stage which can be tackled by using Endosulphan, Chloropyriphos or Phorate granules (in severely affected areas). Root rot affects during the seedling stage and is a major cause of mortality for which a mixture of 2 gm copper Oxychloride and 1 gm each of Bavistin and streptocycline dissolved in 10 litre of water has been shown to be affective. Finally, for control of fungal diseases (Phytopthora, Verticillium wilt, Pythium and Fusarium) seed treatment with Thiram, Vetavax or Bavistin (2gm/kg seed) or Foliar spray and wetting with solution of 1 gm. Bavistin + 1 gm. streptocycline + 2 gm. copper oxychloride per 10 litre water has shown to be affective [5].

JOJOBA OIL AND SEED MEAL PROCESSING:

The average estimated yield of jojoba seeds per plant is around 0.2 - 2 kgs. Depending on the yielding variety and age of the plantation, this accounts for around 2400 kg/acre to 3500 kg/hectare (9 to 10 year-old plantation). On an average around 2000 plants can be planted per hectare [11], [24]. Jojoba seeds are unique among plant kingdom as they consist of nearly 50% by weight of pure liquid wax. It is called as wax not because it is colourless and odourless, but because it does not have any glycerine (glyceridic fat). As reported by Greene and Foster in 1933, its chemical structure is a "straight chain mono esters of monounsaturated C20 and C22 alcohols and acids with one double bond at each side of the ester bond" [25], [26].

Processing of jojoba seeds is a multi-step process consisting of steps like cleaning & grading, dehulling and extraction steps. The process starts by removing any foreign material like sand, dust, and leaves etc. as any foreign materials will absorb oil and depreciate its quality post extraction. It is generally done on revolving screens with reels and shaking devises consisting of strong electromagnet called as cleaner cum grader. Once clean, they are dried for dehulling under sunlight. Dehulling is an important step because the jojoba fruit consists of 40% kernel and 60% shell. When present, hulls absorb significant quantity of oil leading to oil loss. Once dehulled, the mixture of kernel and hull (≈80:20 ratio) is fed in an oil expellers with cooling arrangement. This ratio is important as pure kernel reduces the yield of oil. Similarly the cooling of the expeller is also vital as pressure during extraction produces a large amount of heat (~90°C). This initial extraction using cold press extracts nearly 80% of oil from the mixture and the remaining oil in the cake can vary from 15 - 20%. Using solvent extraction (hexane as solvent) this remaining oil in the cake can be further extracted leaving about 3 to 8% by weight unrecoverable oil [5]. An alternative to solvent extraction is supercritical gas extraction. In a process patented by Stahl and Quirin in 1983, they have used this method for extraction of high grade natural waxes [27] and in another patent by Olberg, they have isolated jojoba oil using CO2 under supercritical conditions [28].

PHYSICO-CHEMICAL DESCRIPTION OF JOJOBA OIL AND CAKE:

jojoba oil has virtually no traces of glycerine which makes it very unique plant based oil. It is a light-golden fluid having low acidity (<2%) with very less requirement for refining [**Error! Reference source not found.** (F)]. Its solubility in common solvents like carbon disulfide, chloroform, benzene, carbon tetrachloride and petroleum ether is high and it is immiscible in acetic acid, ethanol, acetone and methanol. Being rancidity free and non-volatile, it can remain unchanged even after 4 days of heating at 370°C [29]. Kuss et. al. measured the viscosity, density and compressibility of jojoba oil while varying temperature from 25-120°C and pressure from 1 to 2000 bar. He concluded that oleic acid and jojoba oil have same specific conductivity in the temperature range of 34-140°C [30]. Miwa informed that the boiling point of jojoba oil is 418°C but it drops down to 398°C after reaching this critical temperature [31]. In 1975, Wisniak and Liberman measured viscosity, refractive index and density of the oil at different temperature ranges and developed relationships between them (

). Based on these relationships the viscosity index of jojoba oil was calculated to be 225 [32]. To bring its colour to 3 on the Gardner scale, a simple treatment at 100°C with Filtrol-105 for around half hour is suggested [26].

At chemical level, the jojoba wax consists of extremely long (C36 - C46) straight chain entirely of mono-ethynelic linear fatty acids & monounsaturated linear fatty alcohol having high molecular weight. Each constituent molecule has 2 double bonds and 1 an ester group in it. Prevailing fatty alcohols and fatty acids are C-20 and C-22 in length. Its structure is similar to human sebum and whale oil than to traditional vegetable oils. The GLC constituent analysis of oil extracted from Arizona desert jojoba were fatty alcohols tetracosenol 4%, docosenol 21 % and eicosenol 22%, wax esters C40 - 30%, C42 - 50%, C44 - 10% and fatty acids octadecenoic acid 6%, docosenoic acid 7%, eicosenoic acid 35% [33]. **Error! Reference source not found.** and **Error! Reference source not found.** provide data of Ester Composition and structure of fatty alcohols and fatty acids derived from jojoba oil. General properties of the oil are listed in **Error! Reference source not found.**.

Table 4: Relationships between Viscosity, Refractive Index and Density. (t = °C and T = °K). **Source:** [26].

Parameter	Values at Different Temperature Ranges
Viscosity (cP)	0.004995 exp(2646/ *T*)
Refractive Index	1.47391 - *0.000360t*
Density (g/ml)	0.88208 - *0.000655t*

Once the oil is extracted, the remaining cake is a rich source of dietary fibres and can contain up to 25 - 30 % crude protein. Although this is less than what is available in major feed cakes of cottonseed and soybean meals, it contains many important nutrients and has a good potential as animal feed supplement. Exceptions are monogastric animals like poultry because they are less able to digest pentose sugars, which constitute up to 50 % of available sugar the cake. **Error! Reference source not found.** shows the amino acid composition of the cake and **Error! Reference source not found.** shows the chemical composition of jojoba meal.

Although the good potential as feed supplement, jojoba meal has toxicity issues because of the presence of a compound called simmondsin. Due to the harsh environment that the plant grows in, this compound acts as a natural deterrent for grazing animals and is found in seeds, leaves as well as twigs. In 1972, Booth noticed deterioration in health and growth of rats when he started his studies on use of jojoba cake as feed supplement. Death occurred when rats were fed a 15% jojoba meal diet and he saw growth inhibition when he reduced the percentage to 10% [34]. It was Elliger et al who coined the term ‘simmondsin’ in 1973-74 after they isolated and characterised its structure to be 2-(cyanomethylene)-3-hydroxy-4,5-dimethoxycyclohexyl *β*- D-glucoside (C16H25N09) [35]. By 1982 three more minor toxicants were shown to be present in jojoba viz 4,5-didesmethylsimmondsin, simmondsin 2'-ferulate and 5-desmethylsimmondsin [36]. Furthermore, trypsin inhibitors, phenols and tannins have also been seen to be present in it [37]. Mice dosed with pure simmondsin have shown to have a high concentration of cyanide and thiocyanate in blood [38] and Verbiscar *et al* points the finger at aglycon which is produced when simmondsin is broken down by gut bacteria [39].

Much effort has since been devoted to reduce the toxicity due to simmondsin. Microwaving for a short duration has shown to be more effective as it can destroy total phenolic and phytic acid content. Similarly, dry heating at 100°C for 3 h has shown to have reducing toxic effects too. Solvent extraction with isopropanol-water (7:3) has shown to remove nearly 84% of simmondsin and 51% and 28% of total phenolic and phytic acid content respectively [40].

Table 5: GLC Analysis; Composition and structure of fatty alcohols and fatty acids derived from jojoba oil. **Source:** [76].

Alcohols	%	Acids	%
Hexadecanol	0.1	Eicosanoic	0.1
Octadecanol	0.2	Hexadec-7 -enoic	0.1
Octadec-11-enol	0.4	Octadecadienoic	0.1
Octadec-9-enol	0.7	Octadecanoic	0.1
Docosanol	1	Docosanoic	0.2
Tetracos-15-enol	8.9	Hexadec-9-enoic	0.2
Eicos-ll-enol	43.8	Octadec-11-enoic	1.1
Docos-13-enol	44.9	Hexadecanoic	1.2
Eicosanol	Trace	Tetracos-15-enoic	1.3
Hecos-12-enol	Trace	Octadec-9-enoic	10.1
Heptadec-8-enol	Trace	Docos-13-enoie	13.6
Hexacosenol	Trace	Eicos-ll-enoic	71.3
Tetradecanol	Trace	Eicosadienoie	Trace
		Heptadecenoic	Trace
		Nonadecenoic	Trace
		Pentadecanoic	Trace
		Tetracosenoic	Trace
		Dodecanoic	Trace
		Octadecatrienoic	Trace
		Tetradecanoic	Trace
		Tricosenoic	Trace

Table 6: Ester Composition analysis using GLC coupled with HPLC, mass spectrometry and ozonolysis. **Source:** [76].

Wax ester chain length	Alcohol/acid combination	% by GLC & GC-MS
34	18/16	0.1
36	18/18	0.1
	20/16	1.8
38	16/22	0.2
	18/20	1
	20/18	5.4
	22/16	0.2
40	16/24	0.6
	18/22	1.5
	20/20	24.3
	22/18	3.6
	24/16	0.3
42	18/24	1.5
	20/22	10.5
	22/20	37
	24/18	1
44	20/24	0.9
	22/22	2.1
	24/20	7
46	24/20	0.8
48	24/24	0.1
50	26/24	0.02

Table 7: Properties of jojoba oil. **Source:** [77]

Property	Value
Acetyl Value	2
Acid Value	<2
Average MW of wax esters	606
Boiling point at 757 mm under N_2, °C	389
Dielectric constant (27°C)	2.68
Fire point (COC), °C	338
Flash point (AOCS Cc 9a-48), °C	295
Freezing point, °C	10.6-7.0
Heat of fusion by DSC, cal/g	21
Iodine value	82
Iodine value of acids	<76
Iodine value of alcohols	77
Melting points, °C	6.8-7.0
Refractive index at 25°C	1.465
Saponification value	92
Smoke point (AOCS Cc 9a-48), °C	195
Specific conductivity, mho/cm (27°C)	8.86×10^{-13}
Specific gravity, 25°/25°C	0.863
Surface tension, dyne/cm (23.5°C)	34
Total acids, %	52
Unsaponifiable matter %	51
Viscosity	
Saybolt, 100°C, SUS	127
Saybolt, 210°C , SUS	48

Table 8: Amino Acid Composition (%) of two varieties of jojoba meal. **Source:** [78]

Amino acid	Apache 377	SCJP 977
Alanine	0.832	0.953
Arginine	1.56	1.81
Aspartic acid	2.18	3.11
Cystine+cysteine	0.791	0.519
Glutamic acid	2.4	2.79
Glycine	1.5	1.41
Histidine	0.486	0.493
Isoleucine	0.777	0.866
Leucine	1.46	1.57
Lysine	1.05	1.11
Methionine	0.186	0.21
Phenylalanine	0.919	1.07
Proline	0.958	1.1
Serine	1.04	1.11
Threonine	1.14	1.22
Tryptophan	0.492	0.559
Tyrosine	1.04	1.05
Valine	1.1	1.19

Table 9: Chemical composition of jojoba meal. **Source:** [40]

Components * (g/100g dry weight)	%
Moisture	7.18±0.09
Crude protein*	31.89±1.12
Total carbohydrates*	39.78±0.11
Crude fiber*	10.20± 0.14
Total ash*	3.11±0.05
Total simmondsin*	3.33±0.02
Total phenols*	2.67±0.02
Phytic acid*	2.39±0.05

IMPORTANCE OF JOJOBA OIL AND ITS APPLICATIONS:

It was Greene and Foster in 1933 who first reported that jojoba oil resembles sperm whale oil and has more advantages because of various reasons. Less refining requirements, pleasant smell, capability of taking 25% more sulphur than sperm whale oil and not darkening during the process etc. makes this liquid wax an important commodity in a variety of industries. Applications of this oil are much diversified (**Error! Reference source not found.**). Cosmetic industries, pharmaceutical industries, lubricant and petrochemical industries are some of the major utilizers of jojoba oil. These industries and independent researchers have evaluated possible use of jojoba oil in manufacturing of stencils, printing inks, lubricants for high temperature and pressure machineries, greases, carbon papers, cosmetics etc. [41]–[43]. Furthermore, its resistance to oxidation at high temperature and its high dielectric constant make it have its uses in food industry lubricants and as transformer oil respectively. [44]. Along with its medicinal properties, an important use of it comes by being a stabilizer for penicillin. [43], [45].

Applications of jojoba oil can be defined based upon the chemical alterations that can be done on it viz no alterations, attacking double bonds and attacking ester bonds.

For its direct use, Cosmetic Ingredient Review Panel of the Cosmetic, Toiletry and Fragrance Association, Inc. has considered the use of pure jojoba oil as safe in concentrations that are presently used. [46]. Because of its poor digestibility, its potential as a low calorie food supplement has been under evaluation [47] but without much success as shown by Verschuren et. al. where his studies indicated increase in enzyme concentrations particularly transaminase (an important indicator of liver damage) and white blood cells [26], [48]–[50]. Therefore, a lot more work needs to be done in this aspect as low calorie food supplements are the need of the day and the fastest growing are of food industry all throughout the world. On the other hand, for its direct use, it has excellent antifoaming characteristics nearly equivalent to sperm whale oil and it is not metabolised much by the antibiotic producing microbes. [26]. In their study, [51] showed increased yield with usage of jojoba oil with high yield *penicillium* strains. Although not contrary, other authors have reported that jojoba oil offers no advantage in other systems and thus might be advantageous in only some specific systems [26].

Chemically transformed jojoba oil also has many usages depending on the site where the modification is being done. Since it has one ester group and two double bonds a large number of intermediates and final products are possible [26].

Unusual properties of jojoba oil suggest that *cis-trans* isomerization can be used to increase the number of uses of this oil. Since *trans* isomer has a superior stability when compared to *cis* form, soaps made of *trans* isomers have far better quality and usability (wetting and detergency). For geometrical isomerization of the double bond, catalysts like oxides of sulfur dioxide, nitrogen, various phosphorus compounds, tellurium, silicates, selenium, mercaptans, ultraviolet light and electron radiation etc. have been suggested [26] (**Error! Reference source not found.**); of which selenium and oxides of nitrogen have been reported by and of selenium and N02 catalysts by [52]. Galun and Shaubi have studied its photosensitized isomerization as some skin based products are better when photosensitized [53]. High temperature isomerization above 150°C have been done by Brown and Olenberg using acidic bentonite clay and an *all-trans* jojoba oil has been developed by Shani having a melting point of 52-54°C.

Hydrogenation improves a variety of properties of oil. It increases the melting point, softens it and also improves its stability. Even colour and smell of the oil can be improved with it. Warth hydrogenated jojoba oil for use as an ingredient in manufacturing of carbon papers, candles, polish waxes etc and said that candles made using it did not smoke at all and have a bright flame. He did so in a manner similar to that of cottonseed oil hydrogenation and the final product had hard off-white crystalline laminae, was highly lustrous with melting point of 70°C. [54]. Miwa in 1974 compared paraffin wax and polyethylene with jojoba oil. Wisniak and Holin studied its hydrogenation with several nickel and copper chromite catalysts and showed that bleached and unbleached jojoba wax is superior to beeswax. Its X-ray diffraction properties were studied by Simpson and Miwa.

One of the greatest discoveries in the lubrication technology was by Smith in 1939 where he described how sulfurization of sperm whale oil makes it more soluble in paraffinic oils and makes it more stable [55], [56]. This information was used by Ellis in 1936, Flaxman in 1940 and Wells in 1948 on jojoba oil and they reported that jojoba oil can be used as lubricants and extreme pressure additives [57]–[59]. Sulfurized Sperm whale oil has many uses because of the types of properties that it can provide to the end user; non-drying characteristic, metal wetting properties, usage in extreme pressure (EP) conditions, reduced wear rates of machines and gears, low tendency to form sludge on oxidation, compatibility with lead naphthenate are some of the important few [60] [26]. In the US, annul production of sulfurized Sperm Whale oil was around 23 million pounds in 1966 and 30 million pounds before it was banned around 1972 [61].

Table 10: Different catalysts used and their effects on melting points of Jojoba oil. **Source:** [63]

Catalyst	% Trans bonds	Melting point (°C)
Chemical route	>95	52-54
Clays	25	29-31
N02 (purified product)	>95	52-54
NO2	65-75	36-40
Selenium	40-50	36-40

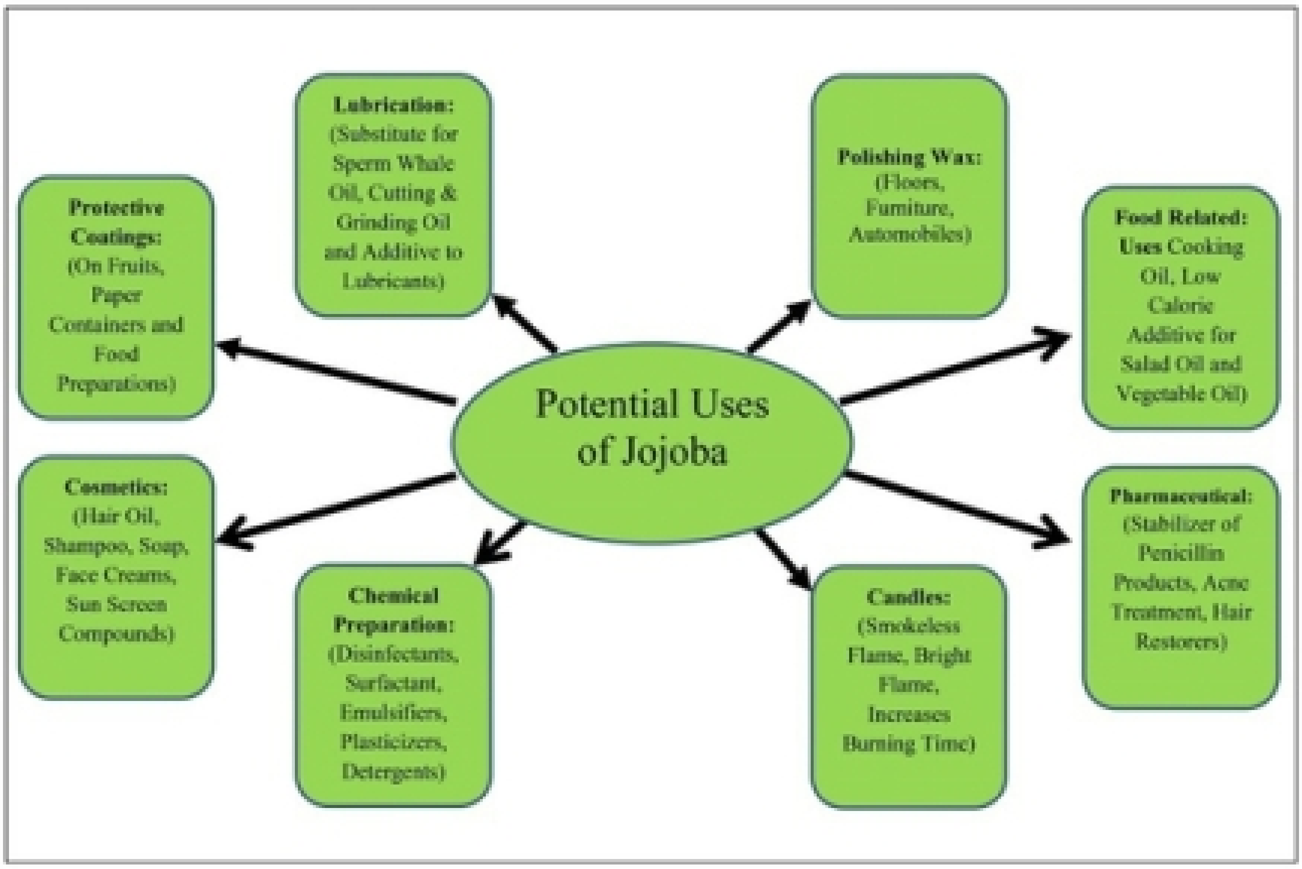

Figure 2: Economic Significance of *S. chinensis*

There are many others who have also researched on a variety of different properties of jojoba oil; Amides that are not available at present can be prepared using jojoba oil as it has a special alcohol composition [26]. Kuss et al. compared different monoester oils with jojoba oil (refined and sulfurized) and measured the effects of high temperature and pressure on their density and viscosity [30]. Mechanical properties of sulfurized jojoba and sperm oil were compared by Gisser et al. and showed that they were nearly equal in improving the load-carrying capacity under EP conditions [62]. Sulfur-brominated and sulfur-chlorinated jojoba oil properties were reported by Wisniak [63]. Phosphonation with different dialkylphosphites of jojoba oil has been reported by Wisniak [63], [64] as dialkyl alkylphosphonates are routeinly used as fuel additives, synthetic lubricants, pesticides and fertilizers, metal extractants, textile treating agents, flame retardants, extreme pressure & antiwear additives etc. [26]. jojoba oil's superior oxidation stability has been shown [65], [66] and its ozonisation has been shown by [67]. In an interesting report, ozonized jojoba oil can treat acne by delivering nascent oxygen directly to the acne microorganism [68]..

CONCLUSION AND FUTURE PROSPECTS:

The new technology that is becoming available for the collection of seeds is helping in reducing the waste by allowing harvesting seeds before they fall on the ground. The time duration of 4 - 8 years that is required for the production of harvest by jojoba is also not much of an issue due to cultivation of annual crops between the rows and diseases are being tackled by new plant biotechnology experts. With the help of high efficiency dehullers and oil expellers, nearly all of the oil can be extracted which further reduces the waste. Similarly, conversion of unproductive plants to productive ones is being done by grafting (especially veneer techniques) with high yield varieties.

Only challenges that are there are related to improving crop variety and reducing the simmondsin content in jojoba cake. Since there are not many requirements for the plant to grow in hardy areas like Rajasthan Desert soil, removal of simmondsin and other anti-nutritional factors like phenols, 4,5-didesmethylsimmondsin, trypsin inhibitors, simmondsin 2'-ferulate, tannins and 5-desmethylsimmondsin should be the major thrust area where the research should be heading. Another area where there is a requirement for engineering and scientific intervention is in improving transplantation conditions of saplings so that they can be transferred from green houses to fields automatically and without any stress. Young researchers have started looking into these areas and once these challenges are met, jojoba production will not only help the industries which requires substitute for Sperm Whale oil, but will also help the animal feed industry.

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