JOJOBA : A POTENTIAL INDUSTRIAL CROP OF MALAYSIA?

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ABSTRACT

Jojoba has generated worldwide interest because its oil is an excellent substitutes for the industrially valuable sperm whale oil. Jojoba is being cultivated commercially or experimentally in widely different climatic conditions. The potential of jojoba as a future Malaysia's industrial crop will depend on further research and development. The purpose of this article is to compile the literature on jojoba and review its status as a potential oil crop. The article describes the distribution, cultural practices, reproduction, pest and diseases, harvesting, yield and uses of jojoba.

1. INTRODUCTION

One of the crops that has received worldwide attention in recent years is jojoba, *Simmondsia chinensis (Link.).* Schneider. Jojoba (pronounced hohoba) has generated much interest among researchers and growers worldwide when the 1933 analysis by the University of Arizona showed that chemical compositions of jojoba oil are almost identical to that of the industrially valuable sperm whale oil. Other factors contributing to this interest are : a) it can be grown in areas of marginal soil fertility, high temperatures, high salinity and low humidity, b) it can be grown and processed with commercially available equipment and c) it has low fertlizer and energy requirements.

Jojoba is being cultivated commercially or experimentally in widely differing environments, from the tropics to the temperate zone. It was estimated that in 1983 there were 15,310 ha of jojoba plantations in the United States of America, 2,025 ha in Mexico with more being established in Australia, Israel, Sudan, and various contries in Latin America, Asia and Africa (Table 1). Jojoba has also been planted experimentally in India, Thailand, Malaysia and Indonesia (17).

The potential of jojoba as an industrial crop in Malaysia will depend on further research and development. The purpose of this article is to compile the literature on jojoba and review its current status as a viable industrial crop.

Table 1 : Area under jojoba cultivation (Ha)

Country	Area, Ha
United States of America	15,310
Mexico	2,025
Costa Rica	1,620
Australia	1,437
Brazil	1,000
Paraguay	1,000
Israel	400
South Africa	344
Argentina	220
Chile	120
Kenya	40

Source : A Benzioni and M. Forti (1989)

2. ORIGIN AND PLANT CHARACTERISTICS

Jojoba has long been considered to be a member of the boxwood family, Buxaceae (6). However many taxonomists are uncomfortable with this designation and claim that jojoba is very different from others in the family that it deserves its own family i.e. Simmondsiaceae. The genus name *Simmondsia* is related to its unique characteristics and the species name, *chinensis* relates to the nineteenth century California-China expedition (22). This species name is misleading in terms of its area of distribution because jojoba is native only to North America. Natural populations of jojoba exist only on the Sonoran Desert of Arizona, California, and northwestern Mexico. Jojoba has not been found growing naturally in any other part of the world (25).

Jojoba is believed to be extremely long lived, from 100 to 200 years under wild conditions (13, 25). The plant ranges in height and width from 1 to 5 m at maturity (13). It has several brittle stems and a strong tap root. In deep soils, the root may be as long as 15-25 m (23). The leaves are usually soft and grey-green during the first year and changing to pale yellow-green after the second year (13).

Jojoba is a dioecious (male and female flowers occur on different plants) evergreen woody plant. In natural habitat, the plant initiates flower buds in late summer and fall. The inconspicuous green and urn-shaped flowers usually occur single at alternate nodes or every node while the male flowers occur in small yellow clusters. The male female flowers vary in number from three to several hundreds. Both male and female flowers lack nectaries and scent glands to attract insects and birds.

The fruits are capsules which change gradually from green to brown on maturation. The capsule may split open to release one, two, or three seeds because each jojoba fruit consists of three carpels. If the ovule in only one of the carpels is fertilized, a single oblong, spherical seed develops per fruit. If two or three ovules are fertilized, seeds have the appearance of one-half or one-third of a sphere section, respectively (25). Seeds also may vary in color and size. The seed size ranges from 700 to 5,300 seeds per kilogram (13, 14). A commercial standard of 1,600 seeds/kg has been widely accepted, and seed of this size is also used as a standard in experimental work (23). At maturity, the seed weighs 0.2 to 1.5 grams and has a diameter of 0.3 cm to 1.3 cm (25). Figure 1 shows clearly the male and female flowers and the fruit of jojoba.

Jojoba appears to be wind pollinated although honey and other native bees may also visit the jojoba flowers (11, 12, 13, 14, 22, 24, 25). Jojoba plant produces large quantities of pollen i.e. 15 g/plant. Pollen grains seen under the microscope have the appearance of deflated spheres. In this state they may be carried away by wind to considerable distances (91 meter). The pollen can be stored for as long as 5 months under liquid nitrogen at - 197°C (13).

3. ADAPTATION AND NATURAL DISTRIBUTION

Jojoba has a wide ecological range of distribution (10). Jojoba populations are distributed over 38,620 km² of the Sonoran Desert of Mexico and the United States between latitudes 25° and 31°N, and longitudes 101 and 117°W (13). Outside its present natural range, jojoba plantations have been established in may countries (Table 1). It can be grown on elevation from the sea level to 1372 m (23, 25). Jojoba plants are found on well-drained and well-aerated soils of a pH range of 5 to 8 (25). Mature plants also can tolerate a temperature as low as - 9.5°C although flower buds are damaged at - 4 to - 5°C (14). Eventhough mature plants will withstand relatively low temperatures, fruit production and vegetative growth can be severaly restricted.

Jojoba plants also can withstand extremely temperatures and severe water stress (1, 2, 3, 9, 13). Although optimum growth occurs in the range of 27 - 36°C, it can tolerate high temperatures of 43 to 46°C when grown under high summer temperatures (13), Al-Ani et al. (1972) said that the ability of the plant to maintain active photosynthesis even at extremely

high temperatures is due, in part at least, to such morphological traits as thickened epidermal cell walls, somewhat depressed stomata, a mesophyll consisting of relatively small densely-packed cells with little intercellular space, and a highly developed root system. Thick cell walls probably contribute to the capacity of the leaves to resist wilting even though subjected to severe drought. Under drought condition, the plant defoliates but resumes growth in the rainy seasons.

Jojoba plants need at least 127 mm of annual rainfall, but areas with 381 to 457 mm of annual rainfall produce the highest yield (11, 13, 25). In areas with about 127 mm of annual rainfall jojoba plants grow 0.9 to 1.22 m in height, but in areas with 254 to 381 mm of annual rainfall, the plants grow to 4.6 m in height (25).

Irrigation is helpful for commercial production especially during the first two or three years of root establishment. The need for irrigation after plants start producing will depend upon the degree to which plants response to such intensive care. The vegetative growth of jojoba plant is greatly enhanced by irrigation (24).

Jojoba plants are very susceptible to low temperatures the first winter (12, 13). However, as the plant becomes older, vegetative growth is less susceptible to freezing (23). Young plants have been severely damaged or completely killed at - 7.2°C for three hours. New growth has been killed at - 2°C (13). Because flower buds are damaged at - 4 to - 5°C, no commercial planting should be made when the winter temperatures drop below - 4°C

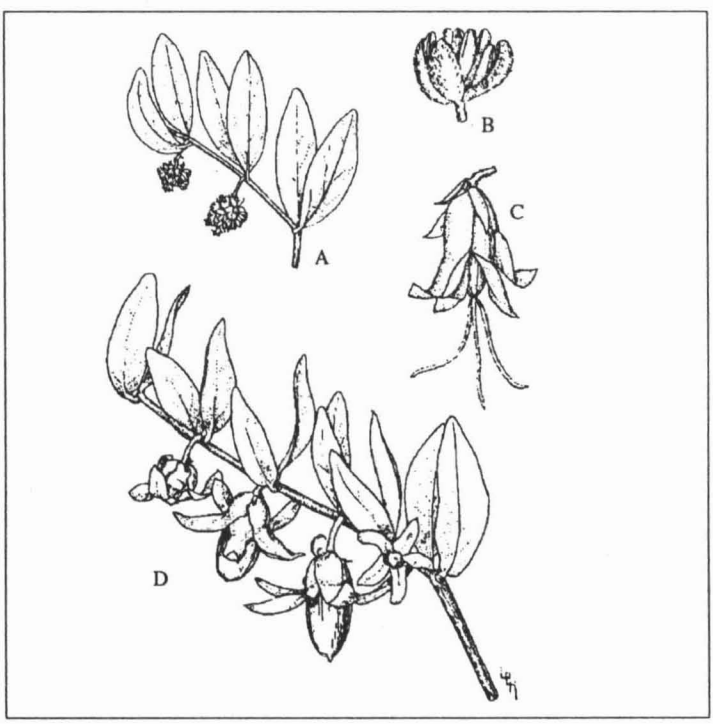


Figure 1. Staminate inflorescence (A),male flower (B), female flower (C),and a branch with fruits (D) of jojoba

Photosynthesis and respiration

Jojoba plants are adapted to the desert environment because they posses mechanisms which enable them to maintain a favorable water and carbon balance during long periods of drought and high temperature. They can endure such conditions because they are rather remarkable in their maintenance of positive net photosynthesis even under low leaf water potential. Positive photosynthesis rates have been measured on field plants even at water potentials as low as - 70 bars (3). Thus, the plant can maintain active photosynthesis rates throughout the day during drought periods. Rates of apparent photosynthesis for well-watered jojoba are normally in the range of 7-11 mg CO_2 /dm^2 /hr (13).

Further, during the high drought periods plants have sharply reduced respiration rates. Thus, by maintaining carbon gain (eventhough at reduced photsynthesis rates) and by reducing carbon loss (low respiration), the jojoba plant maintains a favorable carbohydrate balance. Rates of dark respiration for well-watered jojoba are in the range of 1.5 to 2.5 mg CO_2 /dm^2 / hr (13). The above physiological properties of jojoba and the previously mentioned adaptive morphological features enable the plant to survive desert environment.

4. CULTURAL PRACTICES (PLANTATION)

Planting

If jojoba is to become an important commodity in world trade, it must be domesticated and grown under cultivation (10, 13, 22). This is because the limited yield and unpredictable supplies of wild jojoba can seriously influence the development of new product and market.

Direct seeding is the standard planting practice (13). Seeds are directly placed into the ground at a spacing of 20 to 25 cm in the row and 4 m between rows (14). A planting depth of 3 - 5 cm is considered suitable for good germination (23). Various types of row-crop planters have been used by growers, but vacuum-plate planters give the most uniform jojoba stands (12). The best plants will be later selected to leave a spacing of about 1.5 m between plants in the row with one staminate for each five or six pistillate plants. If a good stand is obtained initially and if the seedling grows vigorously, many common cultural problems can be reduced. In order to achieve good stand, growers must use viable seeds and provide good environmental conditions for high germination rates. The rate of germination is almost 95% and the tap root can be 30.5 to 45.7 cm long before the shoot even appears above the soil (8). The seed grows best in coarse, sandy or gravelly soils with good drainage and aeration and a pH range of 5 to 8 (25). During germination, the seeds must be kept moist and they should be placed at a suitable depth to protect them from being removed by strong winds.

Weed contol

Weed must be controlled during seedling establishment. Weed control has been one of the most costly operations for most growers (13). The weed problem is associated with poor initial stand development. Jojoba seedling are relatively slow in growth the first year especially if the environmental conditions are unfavourable for growth. The weed problem is also associated with the wet condition of the soil. In many instances soils have been kept too wet for too long in an attempt to germinate jojoba seeds. This promotes fast weed establishment and growth. Since jojoba is a new crop, little has been done to develop effective herbicides and to obtain clearance for their use (13).

Moisture requirement

Although jojoba plants have a low moisture requirement, adequate and dependable supply of water must be available to the growers in order to establish and maintain a commercial plantation, especially in areas with low and irregular rainfall. Gentry (1958) said that wild jojoba plant grows best and produces more seeds in areas receiving annual rainfall of 381-457 mm/year although the plant is native to areas receiving about 127 mm of annual rainfall. It is recommended that under Arizona conditions, additional water should be supplied to the plant at the least rate of 14 to 18.7 liters/min/ha during May to avoid soil moisture stress and consequent yield reduction (13). Three methods of irrigation are in use for jojoba : drop, furrow, and sprinkler systems. The surface furrow system is considered to be the most widely adapted system to most areas although the sprinkler system works best on high-water-intake soils (13). Drip irrigation is costly to install and maintain although it has several advantages including: (a) less water loss by evaporation and runoff because water is applied near the roots, and (b) fertilizer could be applied with the irrigation water.

The irrigation water supplied will vary with the stages of plantation development. Two stages of development are recognized i.e. germination stage and plant development stage. During the seed germination stage, frequent light irrigations are needed. During the plant development stage, at least two heavy irrigation per year are required i.e. on spring and fall.

Fertilization

Studies concerning the mineral nutrition and growth of jojoba plants are scarce and have primarily focused on nitrogen fertilization (13). Researchers in Israel have reported that jojoba plants have responded to additional irrigation water and fertilizers. The yield responses of jojoba plants during the 4-year period investigation are shown in the following table (Table 2).

Table 2. Yield responses of jojoba plants to irrigation and fertilization

Treatment	Yield (g of seed/plant)
Control	896
Monthly irrigation[1]	2075
Monthly irrigation + low fertilizer rate[2]	3769
Monthly irrigation + high fertilizer rate[3]	4085

[1]Monthly irrigation rate = 0.5 m3/plant

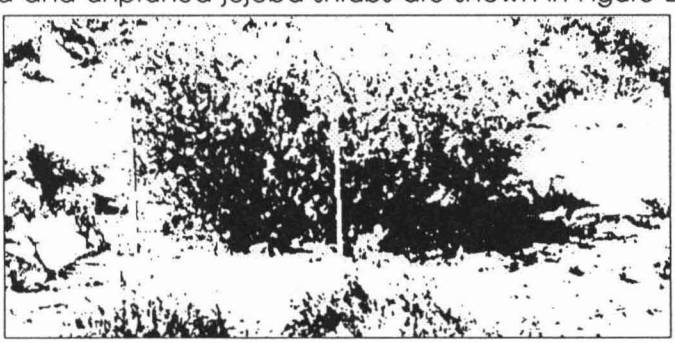
[2]Monthly application of low rate fertilizer containing a mixture of 109 g NH4NO3, 30.1 g 20-20-20 NPK fertilizer and 449 g KNO3

[3]Monthly application of high rate fertilizer=3x lower rates

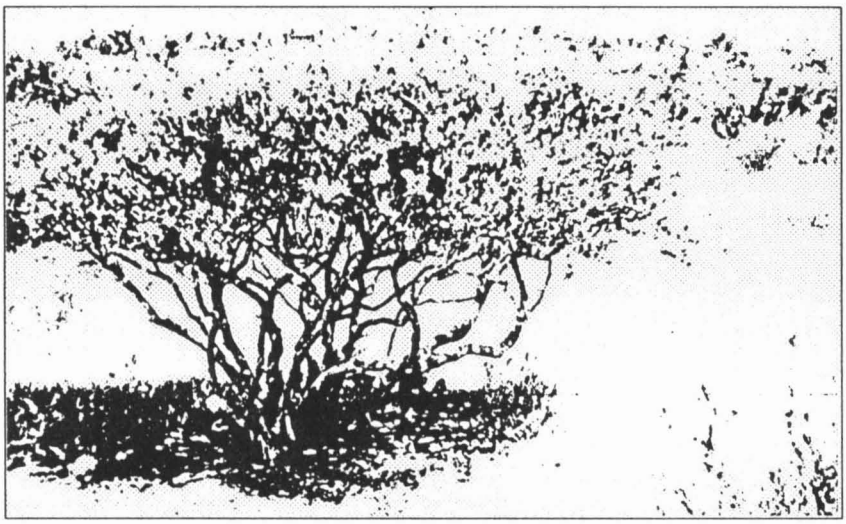
A greenhouse study in California showed that the leaf tissue nitrogen content of a healthy and fast growing wild jojoba plant is about 3%, but that of nitrogen-deficient plant is less than 1%. This shows that nitrogen must be supplied adequately for healthy growth. Since little is known about relationships between nutritional requirement and growth of jojoba plant, further research is needed.

Pruning

Jojoba plants grow with their lower branches so close to the ground that it is difficult to recover fruits that drop off at maturity. Thus pruning is needed not only to facilitate harvesting but also to allow shaking the plant during harvesting to force the clinging fruits to drop to the ground (24). Several of the bottom upright stems and all side branches should be removed to a height of 0.9 to 1.2 meter to give a tree type of growth (25). Both pruned and unpruned jojoba shrubs are shown in Figure 2a and 2b.



(a) Compact, spherical unpruned jojoba shrub



(b) Pruned jojoba shrub

Figure 2. Unpruned and pruned jojoba plants

5. VEGETATIVE PROPAGATION

Vegetative propagation is considered essential to produce high yielding cultivars because jojoba plants grown from seed are very heterogeneous in yield potential. Vegetative (asexual) propagation also ensures the desired male-to-female plant ratio. Jojoba can be propagated by grafting (24), stem cuttings (13, 14), tissue culture (19), and air layering (3).

Research in vegetative propagation of jojoba showed that terminal sections of branches or suckers (with 2 to 4 nodes) which have been treated with rooting hormones can be rooted within 4 to 6 weeks. These cuttings can be planted at a depth of 2 inches in flats filled with vermiculite and kept in a mist chamber at 75-85°F (24). Young and vigorous unstressed stock plants should be used as the source of cuttings because older and woody tissues are more difficult to root. Because seasons affect the rooting potential of the cuttings, cuttings should be rooted during the period of active vegetative growth. High rooting percentages have been found to coincide with periods of active vegetative growth (13).

Yermanos (1974) reported that successful V-grafts can be made between the plant of the same or of different sex by using terminal sections of one-year old branches with 2 to 4 nodes. Another method to propagate jojoba is by air layering. Air layering is a means of rooting stems while the stems are still attached to the parent plant. A ball of moisture-retaining material such as peat moss or sphagnum moss is placed around a section of the stem which has been wounded. The stem is then wrapped with

polyethylene plastic sheet. The rooting of stems can be imporved by applying a combination of IBA and NAA (naphthalene acetic acid). Melendez and Rocha (1982) showed that the highest percentage of rooting in pistillate clones occurred at 0.002 M IBA + 0.02 M NAA, and in the staminate clones at 0.02 M IBA + 0.02 M NAA. They also reported that auxin promotes rooting of stems (4). Gentry (1958) also said that IAA can be used to improve rooting of cuttings. Hogan and Bemis (1983) reported that 4,000-6,000 ppm of IBA is the effective concentration to use to improve rooting of cutting. Stem damage occurrs at IBA concentrations equal and greater than 8,000 ppm. However, researchers in Israel showed that IBA concentrations of 15,000 to 20,000 ppm produced the highest rooting rate. About 60% and 80% rooting of cuttings were obtained from IBA concentrations of 5,000 ppm and 15,000-20,000 ppm respectively (13).

Rooting media

In order to promote root growth, a suitable rooting media must be provided for the cuttings. Many different rooting media have been used with jojoba cuttings. Vermiculite is more effective that sand or a mixture of sand and vermiculite (13). Rooting media containing 1:1 ratio of perlite and vermiculite can also be used (12). Although most jojoba cuttings have been rooted in flats filled with rooting media, some growers prefer to root the cutting in individual container to facilitate transplanting and to prevent transplanting shock. These tranplanted seedlings are used to fill gaps in direct-seeded fields. Bottom heat should be provided and maintained at 25-30°C to promote rooting of these cuttings. In general, cuttings will root between 30 and 60 days (13).

Fertilizer solution must also be added to the rooting media. In Israel, Osmocote is usually incorporated into the rooting medium. Osmocote increases the number of nodes, fresh weight, and succulence of the cuttings (13).

6. PEST AND DISEASES

Diseases

Several potential jojoba diseases have been identified during the establishment of commercial plantings. *Phytophthora parasitica, Pythium aphanidermatum, Rhizoctonica solani* and *Fusarium* sp. were found on decayed roots of young jojoba seedlings grown in unsterilized soil (13). In 1976, one-sixth of the seedlings in a San Carlos Apache Indian Reservation plantation were killed by root rot (8). In another greenhouse study, about 40% of two-to-three month old plants were inoculated with *Phymatotrichum omnivorum* when infected sorghum seeds were buried in the soil near the jojoba roots. The roots were either have symptoms or dead after 7 weeks (13). Jojoba seedlings inoculated with *Verticillium dahliae* become in-

fected as early as 3 weeks after inoculation (13).

In California, about 1.0% of the 9800 rooted cutting had been infected by *Verticillium dahliae* which caused verticillium wilt. The wilt was associated with cotton and barley which had been grown on the field before jojoba cultivation. Severe defoliation has also occured on jojoba cuttings under mist propagation. When examined, the leaf petioles and nodes of cuttings were infected by *Alternaria* sp.(13). Another bacterium that may cause proble is *Coniothryrium* sp. This bacterium has been isolated from wild cuttings. Fortunately these foliar diseases are not a serious problem with cuttings obtained from cultivated plants. Preplant soil treatment must be made to prevent damage caused by *Phytophthora parasitica* and *Pythium* sp.

Pest

The common insect and pest problem of jojoba are caused by moth, leaf hopper (*Homalodisca liturata*), aphids, red spider, rabbits, moles and ants. Aphids seldom require control measures but red spider, ants, moles and rabbits have caused considerable damage in some plantings. Deer and other animals can be a problem especially when other forage is limited. Some of those animals are peccaries, chipmunks, and ground squirrels (8).

7. HARVESTING

Harvesting is done by hand and occasionally with the help of claw-pickers (Figure 3). On the average, 1.8 to 2.7 kg of seeds can be picked per man-hour. Yermanos (1974) said that further improvements in the design of the claw pickers are needed in order to increase the harvesting efficiency.

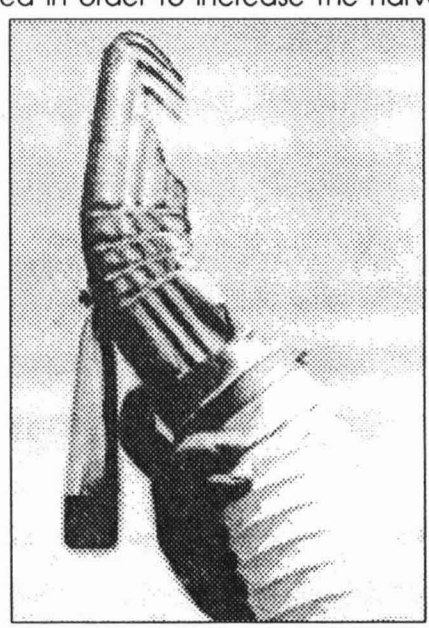


Figure 3. A claw-picker used in harvesting jojoba seeds

In areas with high labor costs, harvesting by hand is uneconomical. Thus, there is a need for mechanical harvesting. Because of large variations in seed maturation and dehiscence, it is extremely important to select plants which mature uniformly to facilitate mechanical harvesting. Several mechanical harvesters have been developed, but the over-the-row, single-row harvester (originally developed for blueberries) is the best choice (13).

8. YIELD

Jojoba plant is grown for its valuable seeds. The seeds of jojoba contain large amount (50-60% of their fresh weight) of intracellular wax esters in the cotyledons (1, 9, 11, 12, 13, 14, 16, 21, 22). Jojoba plant starts to produce seeds when they are 2 to 3 years old. Seed yield from high yielding cultivars is more uniform and higher than yield from wild jojoba plant. In California, average yields from 3-year-old commercial plantations range from 13.6 to 36.3 kg/Ac although one field had produced in excess of 90.7 kg/Ac (25). Hogan and Bemis (1983) reported that 3-5 year old plants at University of Arizona station located in Bakersfield, California, produced an average of 771 g seed per plant, but 7 year old plants at University of Arizona Mesa Experimentation Station produced an average yield of 680 g of seed per plant. Yield in California is higher than yield in Arizona because of ecotypic differentiation. The physiological responses to the climatic factors of available moisture and temperature are very distinctive between plant of the Pacific coast in California and that of the Sonoran Desert in Arizona (3). Conditions in California are more favorable for plant growth than conditions in Arizona.

Yermanos (1983) said that seed yields of 1,361 to 1,814 kg/Ac (about 680 - 907 kg oil per acre) from 7 or 8 year old plantation can be obtain if improved varieties and new planting techniques are used. An average yield of 2-3 kg/tree annually is presently required for profitable production, but as the price of jojoba oil will drop when it becomes more readily available, an average of 3-4 kg/tree should be the minimum target for commercial growers (23).

9. JOJOBA VS SPERM WHALE OIL

The seeds of jojoba contain valuable wax. The wax is not a triglyceride (fat) but a wax ester of high molecular weight. A wax molecule consists of one molecule of a long-chain alcohol esterified with one molecule of a long-chain fatty acids. Jojoba wax consists of two such esters, one with 40 carbon atoms and the other with 42 carbon atoms (25).

Jojoba wax possesses several advantages over the sperm whale oil. The

jojoba wax has no fish odor, and indeed has a mild pleasant odor(25). The wax requires no refining for use in most industrial processes. It has a very high viscosity index and fire points, characteristics that are important to industry. It takse up large amounts of sulfur than sperm whale oil during sulfurization. During the process, jojoba wax does not darken to the same extent as other oils and it remains in liquid form even if highly sulfurized. Sperm whale oil does not remain liquid when highly sulfurized. Another important property of jojoba wax is that it is undamaged by repeated heating to high temperatures. It is also not easily oxidized.

10. USES

The unsaturated liquid wax of jojoba has a wide variety of potential uses. The most important use of the wax is to substitute for the industrially valuable sperm whale oil. Jojoba wax is used as a lubricant for machinery operating at high temperatures and pressure because it maintains its viscosity over a wide temperature when sulfurized. When used as motor oil, it behaves like the new high-perfomance oil which improves fuel economy. It needS to be changed once in every 25,000 miles (22). It is also used in delicate machinery and it improves cutting and grinding processes (22).

Jojoba wax can also become a source of straight-chain, mono-unsaturated alcohols and acids which can be used as intermediates for the preparations of disinfectants, surfactants, detergents, driers, emulsifiers, resins, protective coatings, corrosion inhibitors and the bases for creams and ointments and many other product (13).

Jojoba wax can be hydrogenated to produce high quality candles, floor finishes and polishes. The hydrogenated wax has properties very similar to carnauba wax, the "king of waxes" which is becoming increasing expensive and unsteady in supply (8). Thus, it is thought that jojoba wax could be a substitute for carnauba wax.

Most of the jojoba wax is used in the cosmetic industry (13). It has been widely used in the manufacture of shampoos, conditioners, creams, lipsticks and lotions.

The wax also has pharmaceutical uses as a coating for drugs, and as an antifoaming or stabilizing agent in the manufacture of penicillin (22).

After the oil has been extracted from the jojoba seed, a meal is left and this meal may be used as livestock feed. The meal contains about 30 percent protein (Table 3). However, the meal has appetite depressant monoglucoside called simmondsin. The toxin can be removed from the meal by hot water washing.

Table 3. Amino acid composition of jojoba meal

Amino acids	% Total amino acids in jojoba meal (i.e., grams a/a per 100 grams of meal)	Amino acids expressed as percent of amino acids recovered
Lysine*	1.4	5.7
Histidine	0.6	2.5
Arginine	1.9	7.8
Aspartic acid	2.6	10.6
Threonine*	1.3	5.3
Serine	1.3	5.3
Glutamic acid	3.2	13.1
Proline	1.5	6.1
Glycine	2.4	9.8
Alanine	1.1	4.5
Cystine (half)	0.6	2.4
Valine*	1.5	6.1
Methionine*	0.1	0.4
Isoleucine*	0.9	3.7
Leucine*	1.8	7.3
Tryosine	1.1	4.5
Phenylalanine*	1.2	4.9

* = essential amino acid

The foliage is also a good browse for range cattle. Both the meal and hulls have potential use as high-nitrogen fertilizer or mulch.

Another use of jojoba plant is as an ornamental plant because it has distinctive evergreen blue-green leaves. It is also a valuable soil conservation and lanscaping plant for highways, city parks and rest stops because it is smog tolerant, and water conserving. It also requires little care. In Egypt, jojoba plant is considered a valuable plant to stabilize its ever-encroaching desert (8).

Since the seed are palatable, the Indians eat them raw or the seeds are boiled to provide a well-flavored drink similar to coffee (6).

11. CONCLUSION

Jojoba appears to offer considerable potential for becoming important and profitable new industrial crop. With continued genetic improvement and with vegetative reproduction of superior materials higher yield will be obtained. Much research is needed especially in nutritional requirement, weed control, harvesting, and cost of production. In spite of some diseases and insect problems, the scale of jojoba cultivation seems tipped towards success. This has been shown by the rapid increase in jojoba plantations in the past few years.

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