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Comparison of Properties and Function of Jojoba Oil and Its Substitutes

M.O. Bagby

Northern Regional Research Center
U.S. Dept. of Agric.
Agricultural Research Service
Peoria, IL 61604

Introduction

Waxes and wax-like materials for general use are solids at room temperature. They impart water repellency, hardness, brittleness and a nongreasy feel. Commercial waxes for many traditional uses, for example in paper and candles, are petroleum products. Beeswax and various other natural waxes consist of a mixture of triglycerides, esters, acids, alcohols and hydrocarbons. In contrast, the jojoba plant (*Simmondsia chinensis*) is unique with its seed consisting of about 50% wax esters (97% pure). Resembling sperm whale oil, it remains liquid at room temperature. Both become solids during hydrogenation. The more highly saturated spermaceti wax fraction is a solid, melting at about 45 C (1). Since sperm oil, by law, became unavailable in 1971, various alternative waxes have been considered to meet the market demands formerly satisfied by sperm oil. Jojoba oil was recognized as a leading candidate and, because of its unique characteristics, has been championed as a promising crop for North American as well as world agriculture. By 1984, 40,000 acres of jojoba were established in semiarid regions. In this paper, I examine composition, properties and function of jojoba oil and its competitive substitutes as industrial waxes.

Established Uses for Solid Waxes

Solid waxes have a long history of being used commercially for a variety of applications ranging from paper coatings, candles and water proofing to fruit coatings, crayons and chewing gum. Petroleum-derived materials are now the major sources of commercial waxes, but natural products also are still being used abundantly. Table 1 lists some major uses for a few principal waxes.

Petroleum-based waxes are used for a variety of applications either

TABLE 1

Major Industrial Uses of Solid Waxes (1, 2).

	Wax sources							
Uses	Petroleum	Carnauba	Hydrogenated Castor Oil	Bees	Candelilla	Bayberry	Lanolin	Japan
Paper	X	X	X		X			
Candles	X			X	X	X		X
Electrical equipment	X							
Textile, leather, waterproof	X	X			X			
Floor, cars, shoes	X	X		X				X
Fruit, vegetable	X	X			X			
Cosmetics, pharmaceutical	X	X		X	X		X	
Carbon paper, inks	X	X						
Grease, lubricant, mold release	X	X	X	X	X			X
Chewing gum	X				X			
Adhesive	X				X			
Matches	X							X
Dental wax	X	X		X				
Precision casting	X	X		X				
Explosives	X							
Crayons	X			X				
Confections	X	X		X				
Thermoplastic resin	X							X
Rubber	X							

TABLE 2

Important Physical and Chemical Tests for Solid and Liquid Waxes (1, 2).

Hardness	Hydrocarbon content
Ring and ball softening point	Resin content
Melting point	Saponification number
Cooling curve	Acid number
Congealing point	Iodine number
Ash	Acetyl number
Viscosity	Oil content
Refractive index	Moisture
Specific gravity	Chemical composition
Color	

TABLE 3

Typical Properties of Natural Solid Waxes for Commerce (1, 2).

Characteristic	Beeswax	Candelilla	Carnauba	Japan
Melting point, °C	65	70	85	55
Hardness (penetration)				
(25 C) mm	2.0	0.3	0.2	—
(43.3 C) mm	7.6	—	0.3	—
Viscosity (98.8 C)				
cSt	12	—	35	—
SU[a]	67	—	165	—
Acid number	20	15	5	20
Saponification number	85	55	80	220
Wax esters, %	70	30	85[b]	0[c]
Hydrocarbon, %	15	50	3	—
Iodine number	10	25	10	10

[a]Saybolt Universal.
[b]About one-half aromatic esters.
[c]Mostly tripalmitin.

alone or in blends with other materials. These petroleum waxes are manufactured with a range of physical properties. When considering uses for waxes and planning applications tests, physical properties are of primary concern. ASTM standard methods are used widely for obtaining appropriate data. Some of the more important characteristics have been summarized (1,2) and are here listed in Table 2. Typical properties for representative natural waxes are summarized in Table 3. In compar-

TABLE 4

Chemical Composition of Jojoba (8); Sperm Whale, Winterized (5); Orange Roughy, Black Oreo and Small Spined Oreo (6); and Fermentation Oils (7).

	Jojoba		Sperm whale		Orange roughly		Black oreo		Small spinal oreo		*Acinetobacter calcoaceticus*	
Triglyceride, %	—		33		3		5		2			
Wax ester, %	97		67		95		92		96			
	Acid	*Alcohol*	*Acid*	*Alcohol*	*Acid*	*Alcohol*	*Acid*	*Alcohol*	*Acid*	*Alcohol*	*Acid*	*Alcohol*
10:0			0.1									
11:0			tr									
12:0			2.0								tr	tr
13:0			0.1									
14:0			6.2	3.4	0.6		2.0	1.0	3.4		tr	1.2
15:0			0.4	0.9			0.4		0.4			
16:0			10.6	28.0	0.5	3.6	7.8	10.4	4.0	4.7	27.8	29.1
17:0			0.3	0.8	0.3		0.6	0.4	1.9			
18:0			1.2	4.4	0.2	4.0	1.6	1.2	1.8	0.4	9.2	11.6
19:0			tr	0.1				0.3				
20:0			0.2	0.1			0.1					
22:0			tr									
11:0–19:0 branched			2.0	1.7								
12:1			0.6									
13:1			0.1									
14:1			4.8	0.1	0.2		0.2		0.2			
15:1			0.2	0.1			0.4					
16:1			17.2	6.2	5.9		4.0		5.4		6.2	3.8
17:1			1.0	1.3	0.5		0.4	0.4	1.8			
18:1	5.5	0.6	26.9	42.6	28.0	17.3	13.4	9.5	16.4	11.6	6.8	4.3
19:1			0.3	0.6								
20:1	35.5	22.0	11.0	3.8	8.9	15.3	7.9	14.8	8.2	16.8		
22:1	7.0	22.5	4.6		3.9	6.9	5.8	10.2	4.8	15.8		
24:1	0.5	4.5	0.3			2.7	4.2	2.0		0.6		
16:1–18:1 branched			1.3	0.6								

ison, hydrogenated jojoba wax melts at about 70 C, a value typical for common wax substances. Beeswax and carnauba wax consist of rather high amounts of wax ester, while candelilla wax is about half hydrocarbon. Japan wax is triglyceride consisting of mostly tripalmitin.

Chemical Structures of Liquid Wax Esters

Jojoba oil consists of 97% wax ester (4) and various minor constituents, while sperm whale oil is only two-thirds wax ester (5). Oil contents and chemical compositions are compared in Table 4 with the fish lipids of orange roughy (*Hopostethus atlanticus*), black oreo (*Allocyttus* sp.) and small-spined oreo (*Pseudocyttus maculatus*) (6) and with the wax ester from succinate fermentation of *Acinetobacter calcoaceticus* (7). The fermentation lipid product was isolated as nearly pure wax ester, but the fish lipids consisted of about 95% wax ester. The constituent fatty acids and fatty alcohols from jojoba are mostly 20- and 22-carbon monoenes. The fish wax esters contain appreciable 18-carbon monoene and significant amounts of saturated acids and alcohols. Spencer and Tallent reported that sperm whale oil consists of a variety of saturated and unsaturated acids and alcohols, including positional isomers and methyl-branched constituents (5). The fermentation wax ester consists of mostly 16- and 18-carbon saturated and monounsaturated acids and alcohols. However, the product wax esters are greatly dependent on substrate, temperature and solvent effects (9,10). The products are a function of chainlength of the hydrocarbon substrate, while decreased fermentation temperature leads to increased unsaturation from two-thirds saturates to nearly three-fourths diene when lowering temperature from 30 to 17 C.

Synthetic wax esters were prepared from *Limnanthes* (meadowfoam) oil (11), *Crambe* oil and *Lunaria* oil (12). Since the use of sperm whale oil was discontinued, wax esters have been synthesized from various fatty substances, e.g., soybean oil, linseed oil (13) and lard oil blends with coconut and crambe oils, fractionated tallow and commercial oleic acid (14). The chemical compositions of the lard oil blends were not reported; however, compositions of the other synthetic esters are summarized in Table 5. Alcohols were prepared by sodium reduction of the source fatty acids and then reacted with fatty acids to form the wax esters with random compositions. The meadowfoam products were synthesized from 20- and 22-carbon acids containing the unusual *cis*-5 unsaturation (15,16). Crambe esters are synthesized from 18- and 22-carbon acids, Lunaria esters from 18-, 22- and 24-carbon acids and

TABLE 5

Chemical Composition of Synthetic Wax Esters Made from Vegetable Oils.

	Limnanthes oil (11)	Crambe oil (12)	Lunaria oil (12)	Selectively hydrogenated			
				Soybean oil (13)		Linseed oil (13)	
	Acid			*Acid*	*Alcohol*	*Acid*	*Alcohol*
14:0	tr	0.1					
16:0	0.2	2	1	10.3	10.6	6.7	6.9
16:1	0.2	0.6	0.2				
18:0	tr	2	0.2	4.9	5.6	5.1	6.7
18:1	2	17	25	75.6	74.2	60.6	58.6
18:2	0.2	8	6	9.2	9.6	27.6	27.1
20:0	2	6	0.4				
20:1	65	1	—				
20:2	0.4	5	1				
22:0	—	2	—				
22:1	20	55	45				
22:2	10	—	—				
24:1		1	21				

TABLE 6

Gas-Chromatographic Analyses of Wax Esters for the Four Major Peaks, %.

	Carbon atoms									
Source	28	30	32	34	36	38	40	42	44	46
Orange roughy (6)					17	25	23	15		
Black oreo (6)				12	22	21	20			
Small spored oreo (6)					18	26	25	13		
Sperm whale (6)	14	21	23	20						
Jojoba (17)						7	30	50	10	
Limnanthes (17)						3	45	41	10	
Crambe (17)					12		39	8	31	
Lunaria (17)							29	15	20	19

linseed oil and soybean oil esters from 16- and 18-carbon acids.

The four major components identified by gas-chromatographic analyses are summarized in Table 6 for the natural fish wax esters, sperm whale oil and jojoba oil, as well as for the synthetic meadowfoam, crambe and lunaria wax esters. Jojoba, meadowfoam and crambe have nearly equal average chainlength; however, jojoba wax esters result from a nonrandom combination of acids and alcohols to provide the preferred docosenyl eicosenoate (18). The average chainlengths of the fish esters are intermediate to those of jojoba and sperm whale oils.

Physical Properties of Wax Esters

Wisniak (19) has compiled the available data for physical properties that characterize jojoba oil. Its physical properties and those of other wax esters are summarized in Tables 7 and 8. Although data are not always based on the same parameters, partial comparisons between jojoba and orange roughy oils are possible. Jojoba oil is somewhat more viscous; however, other properties are similar.

The relative oxidative stability of jojoba oil and other wax esters with similar iodine numbers was studied by Hagemann and Rothfus (21). Their data are summarized in Table 9. Jojoba and sperm whale oils had the greater weight gain in the presence of oxygen, and jojoba oil exhibited the more rapid oxygen uptake.

TABLE 7

Physical Properties of Liquid Wax Esters.

	Jojoba (6, 19)	Orange roughy (6, 19)	Limnanthes (11)	Crambe (12)	Lunaria (12)
Refractive index	1.4650, 25/D (20)		1.4602, 40/D	1.4616, 40/D	1.4602, 40/D
Viscosity, cSt					
20 C		39			
25 C	58	33	39	37	40
40 C		20	25 (37.8 C)	24 (37.8 C)	27 (37.8 C)
60 C		12			
80 C		8			
100 C	27[b]	6			
Density kg/l	0.863 (20 C)	0.868 (20 C) 0.871 (15 C)	0.866 (25 C)	0.874 (25 C) 0.863 (37.8 C)	0.864 (25 C) 0.858 (37.8 C)
Pour point, ° C	10	9	5	24	13
Heat of fusion, cal/g	21, 25/D (20)	—	—	—	—
Cleveland open cup					
Smoke point, ° C	195	222			
Flash point, ° C	295	285			
Fire point, ° C	338	320			
Flash point, closed cup, ° C		261			

TABLE 8

Four-ball Test Data (6).

	Jojoba	Orange roughy
Extreme pressure test, 10 sec run		
Mean Hertz load, kg	21	22
Initial seizure load, kg	—	63
Weld load, kg	160	141
Mean wear scar diam, mm		
40-kg load at 75 C, 1 hr	0.76, 70 C (19)	0.66

TABLE 9

Oxidative Stability of Wax Esters—Thermogravimetric Parameters Programmed 5 C/min from 60 C to 200 C (21).

O_2 Wax ester	Oxidation initiation, ° C	Max wt gain, ° C	Wt gain, %	Rate of uptake μg/C
Sperm whale	100	150	0.44	0.15
Jojoba	165	188	0.52	0.66
Limnanthes (synthesized)	146	166	0.30	0.28
Crambe (synthesized)	130	155	0.30	0.32
Behenyl arachidate (synthesized)	115	180	0.30	0.04 (115-165 C)

Commercial Products From Wax Esters

Jojoba oil and appropriate derivatives have been championed for use in numerous and diverse products typical of wax materials. Specific uses mentioned, frequently include: cosmetics, lubricants, extreme-pressure lubricants, cutting oils, pharmaceuticals, low-calorie foods, foam control products, transformer oils, candles, emulsifiers and hydraulic fluids. A similar list of products also have been suggested for other wax ester sources. The Journal of the American Oil Chemists' Society recently summarized the low-calorie food considerations of jojoba and orange roughy oils (22). Considerable testing remains to be done to establish safe levels of consumption. However, results reported in this proceedings are promising. The results of toxicity studies show that for cosmetic purposes jojoba oil is benign (23). Mice force-fed jojoba oil showed no evidence for acute toxicity; rabbits had slight but insignificant eye irritations; and skin patch tests with both guinea pigs and humans showed that jojoba oil can be considered safe for human skin.

Sulfurized products from jojoba oil were equal or better than sulfurized sperm whale oil as an extreme-pressure additive (24). Also, sulfurized derivatives have been prepared of orange roughy (6) and the synthetic wax esters from lard oil and tallow (25), soybean and linseed oils (13) and crambe and limnanthes oils (26,27). Unfortunately, the data are not readily comparable for various reasons (e.g., missing information and different tests or test conditions). However, all investigators concluded that the properties of their sulfurized product were similar to those of sulfurized sperm whale oil.

Various other jojoba oil products have been introduced as lubricant additives. George Arndt (Wynn Oil Co.) holds a patent on isomerized jojoba oil (containing more than 20% *trans* unsaturation) as an additive for automotivecrankcase motor oil (28). Tenneco, Inc., was granted a patent on the use of hydrogented jojoba oil as a corrosion-inhibiting preservative for lubricating oils (29). These formulations impart excellent coatings on the interior metal surfaces of an internal combustion engine. Partially hydrogenated orange roughy wax ester has been formulated as a cold-rolling mill lubricant for manufacturing steel sheets (30).

Other interesting derivatives have been prepared from jojoba wax esters, e.g., hydroxylated, chlorinated and brominated products (31), Diels-Alder adducts (32) and diozonides and their oxidation or reduction products (33). These derivatives have been characterized for structure, but their physical properties have been reported only partially (19).

To develop markets for these derivatives, they need to be further evaluated for physical and chemical properties and in product formulations. Similarly, the various synthetic wax esters could benefit from additional research and in-use testing.

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