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Sea Buckthorn Products: Manufacture and Composition†

Tom Beveridge,*,‡ Thomas S. C. Li,‡ B. Dave Oomah,‡ and Allen Smith§

Food Research Program, Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Summerland, British Columbia V0H 1Z0, Canada, and Panax Q Farm Ltd., Vernon, British Columbia V1B 3C5, Canada

Sea buckthorn (*Hippophae rhamnoides*) is a unique plant currently being domesticated. The fruit is the main component of value, although the leaves are occasionally made into sea buckthorn tea. The two main sources of valuable products are derived from the berries, juice from the fleshy tissue and seed as a single seed from each berry. The juice provides a nutritious beverage, high in suspended solids and very high in vitamin C and carotenes. The juice may contain an oil phase trapped within the suspended solids, or the oil may be removed as pulp oil and provided separately. The pulp remaining after juice removal provides for extraction of "sea buckthorn yellow", a pigment that has potential use as a food coloring material. The seed is a source of seed oil, which is very unsaturated and shows promise, because of its light absorption and emollient properties, as an ingredient in cosmetics, phytopharmaceuticals, or UV skin protectant preparations. It may be prepared by conventional extraction techniques or by supercritical carbon dioxide extraction. The manufacture of the main products derived from sea buckthorn is described, including several examples from the patent literature. The available compositional data for the main products are tabulated to form a comprehensive source of information on the manufacture and composition of sea buckthorn products.

Keywords: *Products; processes; juice; pulp and seed oil; pigments*

INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.) is a unique plant currently being domesticated in several parts of the world. Fruit characteristics, Asiatic geographical distribution, and cultural practices, insofar as known, have been reviewed recently by Li and Schroeder (1996). It is a hardy plant, drought and cold tolerant, useful for land reclamation and farmstead protection. On the Canadian plains >250000 mature trees have been planted mainly for shelterbelts, enhancement of wildlife habitat, and land reclamation (Li and Schroeder, 1996). The plant is reputed to have considerable medicinal value (Li and Wang, 1998) being useful for the treatment of skin disorders resulting from bed confinement, stomach and duodenal ulcers, cardiovascular diseases, and perhaps growth of some tumors. These beneficial effects have made sea buckthorn products, especially its oils, desirable for medicinal and cosmetic purposes. Products on the market from sea buckthorn range from oil, juice, and food additives to candies, jellies, cosmetics, and shampoos (Schroeder and Yao, 1995). The literature describing the formation of these products is both scattered and limited. Nevertheless, the utilization of the sea buckthorn fruits and seeds, presently being grown in Saskatchewan and British Columbia, requires that processing be undertaken to capture the value-added possibilities. What follows is a detailed summary of the available literature on sea buckthorn related to the processing and composition of products by utilizing juice, oil, and leaves.

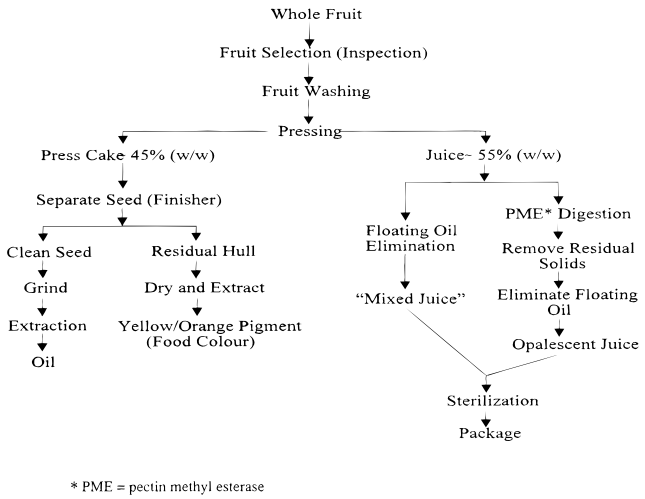

Figure 1. Processing of sea buckthorn berries.

Processing. The total number of publications available describing processing of sea buckthorn berries is rather limited (Zhou and Chen, 1989; Liu and Liu, 1989; Liu et al., 1989; Chen et al., 1995); however, from the available data it is clear that the process is similar to that depicted in Figure 1. There are three main products to be produced: seed oil, yellow pigment, and juice either clarified or unclarified.

Berry Harvesting. Processing begins with the harvesting of berries in the fall. The berries remain on the branches all winter if left undisturbed (Li and Schroeder, 1996). The berry composition varies depending upon growing region, maturity, and harvest date (Li et al.,

* Author to whom correspondence should be addressed [e-mail beveridget@em.agr.ca; fax (250) 494-0755; telephone (250) 494-6363].

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‡ Agriculture and Agri-Food Canada.

§ Panax Q Farm Ltd.

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1998; Zhang, W., et al., 1989). Berries are harvested by hand, although investigations of mechanical harvesters are underway and hormonal treatment to decrease the force required to detach berries looks promising (Li and Schroeder, 1996). The effect of hormones such as ethylene on the processing character of the berries has not been determined, but berry ripening correlates with higher internal ethylene concentrations in the seed (Demenko et al., 1986). This would suggest the berries might display a climacteric respiration pattern. If this proves true, then this fact would have significant consequence for subsequent storage and processing of the fruit. This factor probably deserves attention in the near future.

Berry Cleaning. Berry inspection and cleaning, the next step, is particularly important if fruit is machine harvested. The purpose is to remove diseased and damaged or pest-infested berries and also stems, leaves, or other debris collected during harvesting. This debris would be expected to affect flavor by contributing off-flavors from rotted berries or "green" flavors from leaves and stem material. Washing the fruit prior to juice extraction has been claimed (Liu and Liu, 1989) to be important for removing microorganisms and for removal of dust and dirt clinging to the fresh berry. Sea buckthorn berries are well-known to carry a "musky" odor, detectable even in the sea buckthorn field. The source of this odor has not been investigated, but washing berries prior to processing may provide a method for reducing or adjusting this odor (T. Beveridge, Pacific Agri-Food Centre, unpublished observations, 1999). It appears likely that inclusion of a wetting agent or detergent in the wash water would be beneficial. No studies supporting this contention have been encountered, but one mention of washing in air-agitated tanks has been reported (Heilscher and Lorber, 1996a). The possibility of water pickup during washing was not addressed. The design of washing facilities for sea buckthorn requires attention, and designs may require some method of carrying the berries through an agitated bath. No specific data related to washing have been encountered, except that 40 °C has been suggested for a washing temperature (Zhang, W., et al., 1989). Research in this area may provide dividends.

Juice Extraction. Juice extraction from the berries has not been widely addressed except the casual comment that the berries were pressed (Liu and Liu, 1989). Pressing technologies are standard for the removal of liquid from fruit mash, extensively described by Bump (1989), and there is no reason to suppose that the standard procedures would not work for sea buckthorn berry. The usual press types utilize cloth presses, serpentine belt presses, and screw presses. Rack and cloth and serpentine belt presses are likely to work reasonably well, and apparently give juice yields of ~67% (w/w) (Heilscher and Lorber, 1996b). The possible role of oxidation following processing of sea buckthorn juice has not been addressed, except one reference to oxidation avoidance was encountered (Liu and Liu, 1989). The use of both decanter (horizontal axis) and high-speed (vertical axis) centrifuges for sea buckthorn juice was reported by Zhang, Y., et al. (1989). The use of decanter centrifuges is a recent innovation that allows the continuous extraction of juice from a fruit or vegetable mash stream using centrifugal force (Beveridge, 1997). In principle, it could be used to simultaneously remove suspended solids while removing a floating oil layer from the aqueous phase.

Characteristics of Sea Buckthorn Juice and Treatments. The juice expressed by one of the common pressing techniques is high in suspended solids, providing a very turbid product (Zhou and Chen, 1989). Enmeshed in this juice suspended solid is an oil phase—known as pulp oil. This pulp oil results in the formation of an oil layer on the juice surface, creating an oil ring that remains on the packaging surface. The oil ring remaining on the package is unsightly and undesirable from the consumer's point of view. The content of pulp oil in the juice may be decreased to <0.1%, which eliminates the oil ring problem, by use of high-speed, vertical axis, centrifuges or clarifier centrifuges that operate similarly to cream separators (Zhang, Y., et al., 1989). Removal of the floating oil provides a product termed "mixed juice" in Figure 1. If fresh mixed juice is allowed to stand for 1−2 days, it will separate into three phases: a floating, particulate phase on the juice surface, a fairly clear liquid portion in the middle, and a sinking particulate sediment (Zhang, W., et al., 1989). This separation is apparently undesirable from the consumer's point of view (Kleinschmidt et al., 1996). Removal of this pulp by filtration (Liu and Liu, 1989) or centrifugation (Zhang, Y., et al., 1989) could provide production of one form of sea buckthorn juice.

Alternatively, the freshly extracted (pressed) juice may be treated with a preparation containing pectin methyl esterase (PME) (Liu and Liu, 1989) or perhaps with one of the commercial hydrolytic enzyme preparations. These enzyme preparations contain a mixture of carbohydrate hydrolyzing activities designed to break down the pectinaceous material in the cell wall. Important activities in the mixtures include PME, polygalacturonase, cellulase, and other carbohydrase activities directed toward the arabinose and other carbohydrate polymers making up the cell wall and responsible for its strength and structure. The PME and polygalacturonases are particularly important because they are responsible for hydrolyzing the middle lamella that cements cells together and which is responsible for the viscosity of fresh pressed juice. Hydrolysis of the middle lamella improves juice release from the tissue by reducing juice viscosity and liquifying part of the intracellular material. The reduced viscosity improves removal of suspended solids at later stages of juice clarification. The residual solids may be removed by centrifugation, settling, and filtration (Liu and Liu, 1989). Elimination of any floating oil centrifugally will provide an opalescent juice (Figure 1) or a clarified juice if filtered.

In a patented technique, Heilscher and Lorber (1996b) stated a process for obtaining clear juice, sediment, and oil from sea buckthorn berries. Frozen sea buckthorn berries are washed, thawed, and crushed in a fruit mill. The cold berries are strained through sieves starting at 2 mm diameter and ending with 0.8 mm diameter. The last sieve retains the seeds and some peel, and this retentate may be used to extract seed oil. The remaining mash is heated to 50−55 °C, and the mash is made 5−10% (preferably 7%) in sugar with crystalline sugar or appropriate amounts of fruit juice concentrate. This increase in soluble solids enhances later separation of suspended solids. The mixture is allowed to stand for 1−3 h and then separated by centrifugation into a turbid juice and solid pasty sediment. The pasty mass

Table 1. Composition of Sea Buckthorn Berries/Juice

attribute (units)	range	av	identifn/var.	ref
fruit wt (mg)	270−480	350	cv. Indian-Summer	Li et al. (1998)
fruit moisture content (%)	73.6−85.3[a]	82.3	cv. Indian-Summer	Li et al. (1998)
	72.2−75.5[b]	74.2	Chinese sea buckthorn	Ma et al. (1989)
	61.5−79.4[b]	70.5	Chinese sea buckthorn	Zhang, W., et al. (1989)
juice oil content (%)	0.26−1.43	0.903	Chinese sea buckthorn	Zhang, W., et al. (1989)
	1.8−2.9 (pulp)	2.0	Chinese sea buckthorn	Ma et al. (1989)
specific gravity	1.0275−1.0454	1.03797	Chinese sea buckthorn	Tong et al. (1989)
conductivity ($\mu\Omega$/cm)	0.297−0.539	0.359	Chinese sea buckthorn	Tong et al. (1989)
surface tension (N/m)	46.23−55.14	50.74	Chinese sea buckthorn	Tong et al. (1989)
refractive index	1.3491−1.3566	1.3533	Chinese sea buckthorn	Tong et al. (1989)
total carotenoid (mg/100 g)	9.4−34.5	16.9	cv. Indian-Summer	Li et al. (1998)
	4.6−12.0	7.6	Chinese sea buckthorn	Ma et al. (1989)
	2.0−16.1	6.33	Chinese sea buckthorn	Zhang, Y., et al. (1989)
	16−28			Li and Schroeder (1996)
vitamin C (mg/100 g)	502−1061	709	Chinese sea buckthorn	Ma et al. (1989)
	360−2500			Li and Schroeder (1996)
	1348 (single value)		Chinese sea buckthorn	Liu and Liu (1989)
	513−1676	1038	Chinese sea buckthorn	Zhang, W., et al. (1989)
soluble sugars (°Brix)	9.3−17.3	11.4	cv. Indian-Summer	Li et al. (1998)
	10.83−15.55	13.51	Chinese sea buckthorn	Tong et al. (1989)
	10.19−22.74	15.98	Chinese sea buckthorn	Zhang, W., et al. (1989)
	6.4−12.7 (reducing sugar)	9.0	Chinese sea buckthorn	Ma et al. (1989)
glucose (% of total)	49.5−62.1	54.2	Chinese sea buckthorn	Ma et al. (1989)
fructose (% of total)	37.3−50.4	45.4	Chinese sea buckthorn	Ma et al. (1989)
mannitol (μg/g)	17[c]	na	Finnish sea buckthorn	Makinen and Soderling (1980)
sorbitol (μg/g)	13−640[d]	314	Finnish sea buckthorn	Makinen and Soderling (1980)
xylose (% of total)	0.1−0.7	0.42	Chinese sea buckthorn	Ma et al. (1989)
xylitol (μg/g)	15−91[d]	39.2	Finnish sea buckthorn	Makinen and Soderling (1980)
xylose (μg/g)	13−100[d]	45.5	Finnish sea buckthorn	Makinen and Soderling (1980)
organic acid (% malic)	3.5−4.4[e]	4.0	Chinese sea buckthorn	Ma et al. (1989)
	4.61−7.35[e]	6.05	Chinese sea buckthorn	Zhang, W., et al. (1989)
malic acid (%)	1.11−2.34 (L-malic)	1.85	Chinese sea buckthorn	Ma et al. (1989)
	2.82−6.08	4.57	Chinese sea buckthorn	Zhang, W., et al. (1989)
citric acid (%)	0.042−0.234	0.111	Chinese sea buckthorn	Ma et al. (1989)
tartaric acid (%)	0.013−0.014	0.0135	Chinese sea buckthorn	Ma et al. (1989)
succinic acid (%)	0.236−0.643	0.474	Chinese sea buckthorn	Ma et al. (1989)
D-malic acid (%)	0.015−0.054	0.033	Chinese sea buckthorn	Ma et al. (1989)

[a] Dried weigh. [b] Press juice. [c] Single value, unripe berries. [d] Varies with maturity. [e] Determination as malic acid is a reasonable assumption but is not stated explicitly.

is treated with an enzyme preparation having proteolytic, pectinolytic, and cellulytic activities for 4−6 h at 55 °C, heated to 95 °C, and then separated centrifugally. The juices can be used for mixed juice drinks, nectars, or other fruit beverages. Ultrafiltration clarification provides a clear juice. The remaining macerate is suited for production of fruit preparations and spreads.

Alternatively, the first centrifugation step can be preceded by enzyme digestion followed by ultrafiltration. A clarified juice is obtained as well as digested pulp from which pulp oil can be separated centrifugally.

Juice Composition. The composition of sea buckthorn berries/juice is documented in Tables 1−4. The data are collected from several sources and are derived by various procedures from various regions, which contributes to the widely varying values. Furthermore, sometimes the exact method used to generate the values is not described precisely. Because of this, the individual reports are tabulated separately to reflect and preserve this variation. It is probably too soon to attempt to derive consensus values. Factors contributing to the reported variation include variety, maturity, and growing location (Agafonova and Borodachev, 1986; Zhang, W., et al., 1989; Ma et al., 1989; Li et al., 1998; Tong et al., 1989), but insufficient analysis has been done to define these variable characteristics quantitatively.

Individual fruits weigh 270−480 mg and contain 73.6−85.3% moisture (Li et al., 1998). However, generally less liquid is obtained by dewatering techniques such as pressing, which yields between 61.5 and 79.4%. Apparently, juice yields are normally near 67% by centrifugal procedures (Heilscher and Lorber, 1996b). Juice may contain between 0.26 and 2.9% oil partially bound in the suspended pulp, and this oil promotes floating of a portion of the suspended solids while a second portion of suspended solids sinks to the bottom of the container providing a “three-phase” juice when the raw juice is allowed to stand beyond a few minutes. Physical properties representing specific gravity, conductivity, surface tension, and refractive index are provided in Table 1. The carotenoid pigments in the juice are primarily associated with the suspended solids and oil and are present at levels ranging from 2 to 34.5 mg/100 g of berries, a wide range that probably varies depending on the method of juice production because it would be expected that the levels of suspended solids would also vary with production technique.

The value of sea buckthorn is often based on the nutritional value of its fruit. Vitamin C (ascorbic acid) represents a nutrient of major importance in sea buckthorn juice because it is present in such large quantities (Table 1), ranging from 360 to 2500 mg/100 g of berries (Li and Schroeder, 1996). Considering that fresh orange juice contains 35−56 mg/100 mL (Araujo, 1977), the value of sea buckthorn as a source of vitamin C is apparent. The content of soluble sugars determined refractometrically as °Brix ranges from 9.3 to 22.74 °Brix for sea buckthorn juice (Tong et al., 1989; Zhang, W., et al., 1989), representing a wide range of apparent sugar content. This wide range may be due to the fact

Table 2. Elemental Composition of Sea Buckthorn Berries/Juice

element	range (μg/ml)	av	ref
potassium	100−806	497	Tong et al. (1989)
	0.147−0.209	0.168	Zhang, W., et al. (1989)
calcium	64−256	143	Tong et al. (1989)
	93.9−173	113	Zhang, W., et al. (1989)
phosphorus	82.1−206	131	Zhang, W., et al. (1989)
magnesium	39.8−103	70.4	Zhang, W., et al. (1989)
	53.3−165	88.9	Tong et al. (1989)
sodium	17.7−125	76.9	Zhang, W., et al. (1989)
	18.0−89.8	48.5	Tong et al. (1989)
cobalt	≤0.1		Zhang, W., et al. (1989)
	0.01−0.09	0.034	Tong et al. (1989)
chromium	0.108−0.287	0.178	Zhang, W., et al. (1989)
	0.47−1.00	0.699	Tong et al. (1989)
copper	0.158−0.653	0.384	Zhang, W., et al. (1989)
	<10		Liu and Liu (1989)
manganese	1.17−2.60	1.67	Zhang, W., et al. (1989)
	0.81−3.86	1.27	Tong et al. (1989)
nickel	0.115−0.357	0.237	Zhang, W., et al. (1989)
	0.39−0.09	0.189	Tong et al. (1989)
strontium	0.19−0.616	0.429	Zhang, W., et al. (1989)
	0.08−0.45	0.195	Tong et al. (1989)
vanadium	0.002−0.009	0.0069	Zhang, W., et al. (1989)
iron	4.13−10.9	7.58	Zhang, W., et al. (1989)
	5.93−161	28.2	Tong et al. (1989)
molybdenum	0.03−0.058	0.044	Zhang, W., et al. (1989)
	1.18	1.18	Tong et al. (1989)
zinc	0.431−1.25	0.763	Zhang, W., et al. (1989)
	2.09−6.31	3.29	Tong et al. (1989)
tin	0.045−0.259	0.170	Zhang, W., et al. (1989)
selenium	7.96−11.3	9.21	Zhang, W., et al. (1989)
	0.94−1.11	1.02	Zhao et al. (1989)
boron	0.43−1.38	1.06	Zhang, W., et al. (1989)
barium	0.168−0.362	0.244	Zhang, W., et al. (1989)
aluminum	2.2−16.7	7.88	Zhang, W., et al. (1989)
titanium	0.103−0.814	0.407	Zhang, W., et al. (1989)
lithium	0.132−0.303	0.203	Zhang, W., et al. (1989)
	0.06−0.15	0.09	Tong et al. (1989)
cadmium	<0.05	<0.05	Zhang, W., et al. (1989)
	0.002−0.015	0.0048	Tong et al. (1989)
arsenic	<0.5	<0.5	Liu and Liu (1989)
lead	0.431−0.761	0.551	Zhang, W., et al. (1989)
	<1	<1	Liu and Liu (1989)
	0.06−0.27	0.010	Tong et al. (1989)

Table 3. Amino Acid Content of Chinese Sea Buckthorn According to Zhang, W., et al. (1989)

amino acid	level (mg/100 g)	amino acid	level (mg/100 g)
aspartic acid	426.6	glutamine	19.4
proline	45.2	isoleucine	17.4
ammonia	41.8	glycine	16.7
threonine	36.8	histidine	13.7
serine	28.1	tyrosine	13.4
lysine	27.2	arginine	11.3
valine	21.8	cysteine	3.3
alanine	21.2	methionine	2.3
phenylalanine	20.0		

that the time of harvesting berries, in the fall when it matures or in the winter after it has frozen, provides a seasonal variation of composition (Agafonova and Borodachev, 1986). On average there is a little more glucose than fructose, and xylose provides the minor sugar. The presence of the sugar alcohols mannitol, sorbitol, and xylitol at low levels has also been observed (Makinen and Soderling, 1980). Quantitatively the most important organic acid is malic acid, but there are relatively minor quantities of citric, tartaric, and succinic acid contributing to titratable acidity. The acid values given in Table 1 as organic acid probably represent titratable acidity as percent malic acid, although it is not explicit from the papers. The other values of named acids refer to the actual levels of the specific acids.

Table 4. Composition of the Retentate and Permeate Following Separation from Sea Buckthorn Berry Raw Juice Using Cellulose Acetate Membranes

characteristic	raw juice	retentate	permeate
dry substance (%)	6.5	16.80	5.25
pH	2.7	2.7	2.7
lipid (%)	0.83	7.90	0.0
protein (%)	0.80	4.18	0.37
acid (tartaric acid) (%)	4.22	4.20	4.15
reductive sugar[a]	0.70		0.72
β-carotene (mg %)	2.10	21.62	0.004
vitamin C (mg %)	105.3	109.2	70.0

[a] Following inversion as glucose. From Bock et al. (1990).

There are many elements and trace elements in sea buckthorn. As listed in Table 2, which is a synopsis of the levels of individual elements contained either in the sea buckthorn berries or in the juice expressed from the berries. Bounous and Zanini (1988) found that fruit maturity affects N, Ca, K, Na, Mg, Cu, Fe, Zn, and Mn contents. Harju and Ronkainen (1984) reported that the trace elements found in liqueurs prepared from sea buckthorn included Al, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Rb, and Zn. Sea buckthorn also has a large number of free amino acids as shown in Table 3. Each berry contains a seed weighing, on average, 16 mg, containing 11.0% (w/w) moisture and 14.2% (w/w) oil (Table 5).

Juice Preservation. For preservation purposes, it is necessary that the juice be sterilized. This can be accomplished by thermal treatment, but high-temperature−short-time (HTST) processes (80−90 °C, several seconds) are preferred (Liu and Liu, 1989; Zhang, W., et al., 1989). This is because the juice is somewhat delicate and will give loss of flavor and development of off-flavor if heated beyond the conditions indicated. Also, vitamin C is destroyed by heating, so maximum retention of vitamin C in the juice is enhanced by the HTST conditions. The juice was reported to turn brown after 6 months at 15−20 °C, and this browning was reduced under nonoxidative conditions. Reducing storage temperatures to 4 °C also prolonged the storage life (Liu and Liu, 1989). Enzymes and sunlight were reported to be important sources of browning by Zhou and Chen (1989), who also noted that antioxidant addition was beneficial. These observations are important for juice marketing because there is a very definite indication of limited shelf life. It is not clear if the brown color develops as a result of residual enzyme, such as residual polyphenol oxidase, or if the brown color develops because of nonenzymatic (Maillard or vitamin C) browning. Clearly, however, packaging should be considered that limits or eliminates contact of the juice with oxygen, and low-temperature distribution might be considered. Chemical preservation using potassium sorbate (0.45−0.5 g/L) has also been reported (Lange et al., 1991).

Juice Products. The juice may be prepared from the freshly pressed juice as a turbid or opalescent beverage (Zhou and Chen, 1989; Heilscher and Lorber, 1996a; Heilscher, 1997; Kleinschmidt et al., 1996). Freshly pressed juice is a complex mixture of fluid, suspended solids (cloud), and oil and is therefore a three-phase system that requires stabilization for most acceptable products. The size of the cloud particles in raw juice ranges from 0.5 to 800 μm, which includes fruit particles and entrained oil droplets (Kleinschmidt et al., 1996). Additionally, air may be entrained in the cloud particu-

Table 5. Some Characteristics of Sea Buckthorn Seed and Oil

attribute (units)	range	av	ref
seed wt (mg)	11−24	16	Li et al. (1998)
seed moisture (%, w/w)	5.43−21.9	11.0	Li et al. (1998)
seed oil (%, w/w)	9.69−20.2	14.2	Li et al. (1998)
	7.4−9.9	8.4	Ma et al. (1989)
	8−12		Li and Schroeder (1996)
	6.47−10.5	8.76	Zhang, Y., et al. (1989)
carotenoid content (oil) (mg/100 g)	314−2139	1167	Zhang, Y., et al. (1989)
from seed oil	50−85		Mironov (1989), Caucasus variety
from pulp oil	330−370		Mironov (1989), Caucasus variety
from seed coat oil	180−220		Mironov (1989), Caucasus variety
from seed oil	trace		Mironov (1989), Pamirs variety
from pulp oil	900−1000		Mironov (1989), Pamirs variety
vitamin E (mg/100 g)	40.1−103.0	64.4	Ma et al. (1989)
from seed oil	61−113	92.7	Zhang, W., et al. (1989)
from juice oil	162−255	216	Zhang, W., et al. (1989)
from residue	390−540	481	Zhang, W., et al. (1989)

late, incorporated by the juice extraction process. The presence of the oil droplets and air bubbles provides for the separation of phases in the raw juice described previously. Additionally, the presence of oxygen in close proximity with the oil phase enhances the possibility of oxidation of the highly unsaturated sea buckthorn oils. The use of neutral hydrocolloids will thicken the aqueous phase, emulsify the oil phase, and retard phase separation for considerable time (Heilscher, 1997; Zhou and Chen, 1989). Emulsifiers may also be used to ensure no oiling of the juice beverage (Zhou and Chen, 1989). The combination of emulsifier, neutral hydrocolloid stabilizer, and homogenization apparently gives a product with good stability. The previous comments related to browning during storage should be taken into account as well as the enhancement of oxidation possible by air entrainment.

Increasing the fluid viscosity of the liquid phase by incorporating pectin or xanthan gum achieves drink particle stability, but the increased viscosity produces an unpleasant mouth feel and the refreshing character of the beverage is lost (Kleinschmidt et al., 1996). Using a "ready-to-drink" juice made by diluting raw juice with 5% sugar solution, Kleinschmidt et al. (1996) were unable to produce a stable drink by either Ultra-Turrax high-shear blending, colloid milling, or high-pressure homogenization. There appears to be conflict in the literature regarding the desirability of using hydrocolloid thickeners in the production of sea buckthorn drink products. The thickening may increase stability but produce an undesirable mouth feel.

Heilscher (1995) teaches a method of producing a fruit drink, fruit juice mixed drink, or fruit juice mixtures containing sea buckthorn products, obtained by pressing, straining, or maceration, which do not separate into three phases and in which there is no "ringing" defect due to the suspended oil phase. In its preferred form the product consists of 12−25% (w/w) sea buckthorn juice (4−10 °Brix), 0.05−0.2% (w/w) xanthan, 0.05−0.1% (w/w) 3-sodium citrate, 8−12% (w/w) sugar, and remainder water. The pH of the resulting drink should be 2.7−3.2 and have an acid content of 3.1−9.5 g of tartaric acid per liter of juice. The sugar can be substituted with various fruit juice concentrates. The mixture may be centrifuged but will be homogenized, deaerated, heated to 90−95 °C, and hot filled at this temperature. Heilscher and Dabendorf (1997) further teach the use of a hot water (90−100 °C) extract of the pulp or fruit from *Hibiscus esculentus* L. This extract contains various neutral polysaccharides and is proposed to stabilize juices containing three phases, especially sea buckthorn. Thus, a mixture containing extracted hibiscus fruit is mixed with sea buckthorn fruit or macerate and sugar. The mixture is homogenized in a colloid mill, deaerated, and filled into containers. Presumably, centrifugation could be inserted into the procedure to provide removal of large pieces and a product of increased clarity. Final pasteurization and hot filling at 90−95 °C presumably would complete production of the product.

Lange et al. (1991) describe the characteristic flavor of sea buckthorn as "whey-like" and indicate that it is unpleasant to consumers. They attribute this flavor to flavor precursors such as saturated and unsaturated fatty acids and carboxylic acids (C_3−C_{18}) claimed to exist in sea buckthorn in various concentrations. These flavors are particularly obvious and unpleasant in fruit that has become over-ripe or has been stored too long. This raises the question of the ethylene effects discussed previously (Demenko et al., 1986). The essence of the procedure claimed to overcome this defect is to incubate the sea buckthorn macerate with fairly large cut pieces of raw, intact, healthy, acid-rich fruit (apples, quinces, pears, strawberries, red currants, bananas, etc.) under sterile conditions, in the presence of a preservative such as potassium sorbate for 24 h to 6 weeks. The mixture is further processed to products after the procedure has removed the objectionable flavor. It is claimed that enzymes in the acid-rich fruit degrade the flavor precursors to provide the flavor-improved product.

Within the context of the present literature review, it is evident that most sea buckthorn juices are of the opalescent or cloudy variety. This is not surprising because sea buckthorn press juice is naturally cloudy, and the particulate in cloudy juices carries the color and many of the compositional components of the juice that provide its unique nutritional character (Zimmer et al., 1996). Natural cloud is important for the production and sale of "natural" apple juices (Zimmer et al., 1996; Markowski, 1998) and several types of tropical juices such as guava, mango, or banana (Carle et al., 1998). Consumers of these products expect that the products will be homogeneously cloudy and will not cream or settle within a reasonable consumption period. Cloud material will settle more or less quickly depending on particle size; however, in practice it is found that particles $<0.5\ \mu$m in diameter are likely to be stable in suspension (Zimmer et al., 1996). For example, the mean particle diameter in apple juices showing stable cloud is always between 0.4 and 0.57 μm, averaging 0.49 μm (Zimmer et al., 1996).

To assess cloudy juice stability, Zimmer et al. (1996) describe a cloud stability test based on the centrifuga-

tion of juices at 4200*g* for 15 min. The degree of turbidity obtained after this treatment, as determined by a turbidimeter, accurately predicted the turbidity obtained in the original juice after 1 year of storage. This turbidity value when compared to the turbidity of the original juice provides an estimate of the likely stability of the juice. This test is based primarily on particle size and should be applicable to all cloudy or opalescent juices.

Cloudy juices are very commonly extracted by either presses or centrifugation, commonly decanter centrifugation. Centrifugation through clarifying (vertical axis) centrifuges is used to adjust particle size and enhance particle stability. Because sea buckthorn is usually produced as an opalescent or cloudy juice, it seems likely that centrifugation, through both decanter and clarifier centrifuges, may play an important role in manufacture. This observation has implications for process development and the costs of implementing processes developed.

Contrarily, Bock et al. (1990) teach a method of clarification of pressed sea buckthorn juice by ultrafiltration through a cellulose membrane of molecular weight cutoff at >100000. A clear, oil-free permeate and a retentate enriched in oil and particulate solids was obtained. The composition of the three products is displayed in Table 4. Most of the values are in agreement with literature values (see Table 1), but of particular note is the pH of 2.7 and the relatively high protein levels in the juice. In naturally cloudy apple juice, proteins are the true cloud-forming components (Stahle-Hamatschek, 1989). It would seem prudent to explore the cloud-forming potential of this protein in sea buckthorn. Extraction of the protein from the particulate material by heat or physical treatments such as shear homogenization may provide a source of stable cloud in liquid sea buckthorn products.

The clarified permeate and solids-rich retentate may be used for product formulation either alone or recombined together in various proportions. Thus, 9 L of permeate and 1 L of retentate can be combined with 8.57 kg of saccharose and 0.060 kg of dry apple pectin in 45.7 L of water. The mixture is homogenized, pasteurized, and packaged in various ways. Other possibilities exist including blending with vegetable juices such as carrot juice.

Pigment, a Byproduct from Sea Buckthorn Berries. A pigment, "sea buckthorn yellow", may be extracted from the berries, pressed juice, or pulp (Figure 1). As a byproduct it would seem most useful to use the residue remaining after the juice was extracted. Details of manufacture are somewhat sketchy; however, two processes can be discerned from the literature. In the first description the pigment is extracted by a low-percentage alcohol, probably ethanol (Chen et al., 1995; Liu et al., 1989), after the juice or residue was adjusted or concentrated to be 11−13 °Brix. Alternatively, the juice may be concentrated to 11−13 °Brix at 48−52 °C. In either case the resulting solution is concentrated by spray-drying to yield a yellow powder. The powder is said to be water, alcohol, and acetone soluble and soluble in several petroleum-derived solvents. It contains mainly flavones but also carotene and vitamin E. In alcohol solution it absorbs light maximally at 213, 315, and 445 nm (Liu et al., 1989) or at 450 nm in aqueous solution (Chen et al., 1995). The color is stable to acid but unstable in base, and heating to 80−100 °C causes slow degradation of color. Acute toxicity testing with mice suggested no acute toxicity associated with the pigment extract. The pigment should be suitable for coloring pharmaceutical or cosmetic creams or for addition to foods where yellow-orange colors may be desirable such as ice cream or water ices. It is not clear if the color would substitute for the color of natural orange, but this may be another possibility.

German workers have reported the extraction of yellow carotenoid pigments from sea buckthorn waste using supercritical CO_2. Pressure had the greatest influence on extraction, with yields increasing with extraction pressure. Yields also increased with increasing volume of extracting CO_2 (Messerschmidt et al., 1993). A yield of total carotenoid of 64% was achieved under processing conditions of 60 MPa, 85 °C.

Jann et al. (1997) describe an extract of sea buckthorn berries, juice, or leaves capable of increasing the freezing point of food. The extract is an ice nucleating agent or activity consisting of a protein and a protein−lipid aggregate isolated from sea buckthorn with an aqueous solution containing a saccharide or containing pectin alone or in combination with another saccharide.

Table 6. Fatty Acid Composition of Oil Triacylglycerols of Sea Buckthorn (*H. rhamnoides*)

	seed oil			pulp oil	
	Johansson et al. (1987a)	Mironov (1989)[a]		Mironov (1989)	
fatty acid[b]	mol %	Caucasus (%)	Pamirs (%)	Caucasus (%)	Pamirs (%)
14:0	0.1				
15:0	0.2				
16:0	6.8	20	17	38	38
16:1(*n*-7)	0.4	5	20	14	50
18:0	1.8	3	1		
18:1(*n*-9)	12.7	13	19	33	12
18:1(*n*-7)	2.7				
18:2(*n*-6)	34.7	40	29	15	1
18:3(*n*-3)	38.5				
20:0	0.5				
20:1(*n*-9)	0.2				
20:2					
20:3					
22:0	0.1				
others	1.4				

[a] Seed lipids contain ~8% of 7-oxononanic acid [see Degering (1963) for nomenclature] and lipids claimed to contain vitamins A, E, and P. [b] Nomenclature (e.g., *n*-9) indicates the position of the first double bond from the methyl carbon (methyl carbon = 1).

Sea Buckthorn Oil. The oils from sea buckthorn vary in their vitamin E content depending on whether they are derived from seed oil (64.4−92.7 mg/100 g of seed), juice oil (216 mg/100 g of berries), or the pulp after juice and seed removal (481 mg/100 g of berries) (Table 5). Clearly, from the point of view of delivering maximum vitamin E to the consumer, as much residue should be suspended in the juice as is technically possible without unsightly settling of the suspended solids. Carotenoids (Table 5) also vary depending upon the source of the oil. Mironov (1989) indicated the carotenoids to consist of ~20% β-carotene, ~30% γ-carotene, and ~30% lycopene as well as ~15% oxygen-containing carotenoids. The tocopherol (vitamin E) fraction was made up of ~50% α-tocopherol, ~40% β-tocopherol, and ~10% γ-tocopherol (Mironov, 1989). The fatty acid composition of the seed and pulp oils is shown in Table 6 in either mole percent (Johansson et al., 1997a) or percent (Mironov, 1989) terms. Negative-

ion chemical ionization mass spectrometry confirmed the dominance of C_{18} fatty acids in the fatty acid profile of sea buckthorn seed oil (Johansson, 1997b).

Oil Composition. The composition of the oil extracted from the seed or pulp of the sea buckthorn berry is shown in Table 6. The seed oils are highly unsaturated with up to 73% or more of the fatty acids making up the oil being linoleic or linolenic acids (Lu, 1992). Pulp oil is more saturated with ~38% of the fatty acids making up this oil being palmitic acid, and 14−50% of the fatty acids were palmitoleic acid. The difference between seed and pulp oils seems to lie in the relatively high content of C_{16} fatty acids in the pulp oil and the relatively high proportion of C_{18} fatty acids in the seed oil. Frank and Muller (1993) analyzed the fat of fruit and seeds and found 47 and 21% saturated fatty acids and 53 and 39% unsaturated fatty acids, respectively. These numbers agree with the data in Table 6 in general and emphasize the differences between pulp and seed oils in terms of unsaturation, but they also emphasize the unsaturated nature of the oils. The next most important fatty acid is oleic at 13−19% (seed oil) and 12−33% (pulp oil), underscoring the highly unsaturated nature of the oils in both the pulp and seed. This is important from a consideration of potential shelf life because oxidation can be expected to be a major mechanism of degradation, and packaging of product containing even traces of oil must take account of this reality. Both the pulp and seed oils are highly unsaturated, although the composition varies between oils from the two sources (Mironov, 1989) (Table 6). The seed oil composition described by Johansson et al. (1997a,b) was obtained by extraction with chloroform/methanol (2:1, v/v) mixture, and cleaned up with Florisil extracted with hexane/diethyl ether (4:1, v/v), and measured as the methyl esters gas chromatographically. They also reported a small amount of the unusual oleic acid isomer having the double bond seven carbons from the methyl carbon, while Mironov (1989) reported 8% 7-oxononanic acid. The presence of these unusual acids in sea buckthorn oil awaits confirmation by future analyses. An unsaponifiable fraction was obtained (1−2%) for seed oil and (0.3%) for pulp oil (Mironov, 1989).

Sea Buckthorn Seed Oil Properties. Sea buckthorn seed oil is yellow and sometimes carries an odor referred to as a "fishy" off-note. It possesses very desirable physical properties (Table 7; Figure 2) for use as topical cosmetics, cosmeceuticals, and neutraceuticals. Sea buckthorn seed oil absorbs strongly in the UV-B range (290−320 nm; Figure 2) and may therefore be used as a natural sunscreen absorber. The yellow color reflects the high carotenoid levels (Table 5) as well as a number of pigmented compounds removed during conventional refining, bleaching, and deodorization processing. The absorbency of these colored compounds is low relative to the absorbency of the chromophores, resulting in UV absorbance; absorbance in the visible region is virtually undetectable when the oil is diluted sufficiently to provide data in the UV region of the spectra (Figure 2). The high conjugated dienes, ρ-anisidine, and peroxide values suggest low stability to atmospheric oxygen, consistent with the high level of unsaturation displayed by the oil fatty acids (Table 6). The susceptibility to decomposition during storage and heating is high as indicated by the high peroxide value and unsaturated fatty acids, and the oil is likely to also have a low tolerance to reheating. The saponification

Table 7. Physicochemical Characteristics of Sea Buckthorn Seed Oil, Cv. Indian-Summer (Oomah, 1999)[a]

characteristic	mean value	SD
color, absorptivity (L/g·cm)		
232 nm	2.89	0.03
270 nm	0.64	0.02
303 nm	0.41	0.02
410 nm	0.06	0.02
diene value	3.16	0.01
triene value	0.070	0.002
p-anisidine value	34.19	0.06
peroxide value (mequiv/kg)	20.68	0.06
saponification number	190	1.63
viscosity (mpas·s)	44.0	0.5
carotenoid content (mg/100 g)	41.1	13.4
tocopherol content (mg/100 g)		
α	155.0	7.0
β	16.4	1.7
γ	134.9	2.8
δ	11.3	1.4
vitamin E equiv (mg/100 g)	175.0	8.0

[a] B. D. Oomah, Pacific Agri-Food Research Centre, unpublished observations, 1999.

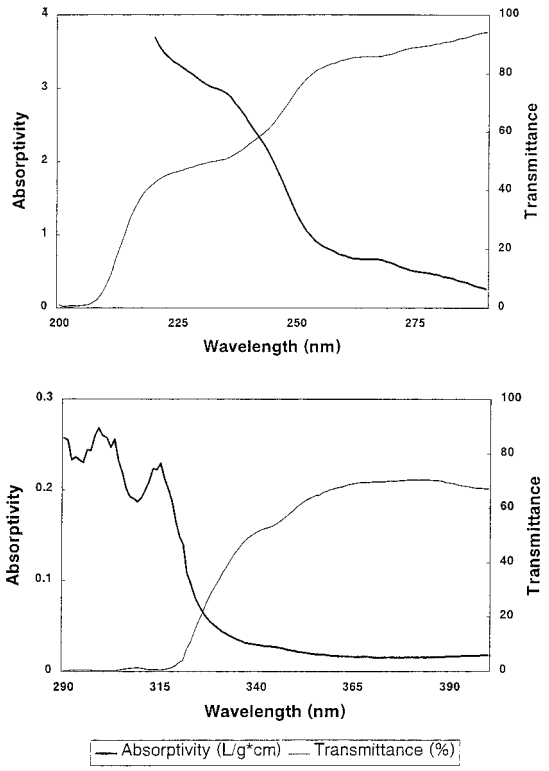

Figure 2. UV−vis spectra of sea buckthorn seed oil: (top) from scans (λ = 200−290 nm) of oil diluted 1:10000; (bottom) from scans (λ = 290−400 nm) of oil diluted 1:100, both in hexane.

value of sea buckthorn oil is comparable to those of more common vegetable oils, and the low viscosity would provide sensory "lightness" to the oil if used in salad dressings or vinaigrettes.

A most significant potential healthful effect of sea buckthorn seed oil lies in the high content of α-tocopherol, which is recognized as the natural antioxidant in the human body. It is thought that high levels of tocopherol minimize lipid oxidation, maintaining tissue integrity and reducing skin toughening and wrinkling. This proposed, unique, property of sea buckthorn oil, conferred by the high tocopherol level, is being recognized and sought by the cosmetic industry. Potentially, sea buckthorn oil will become an important component

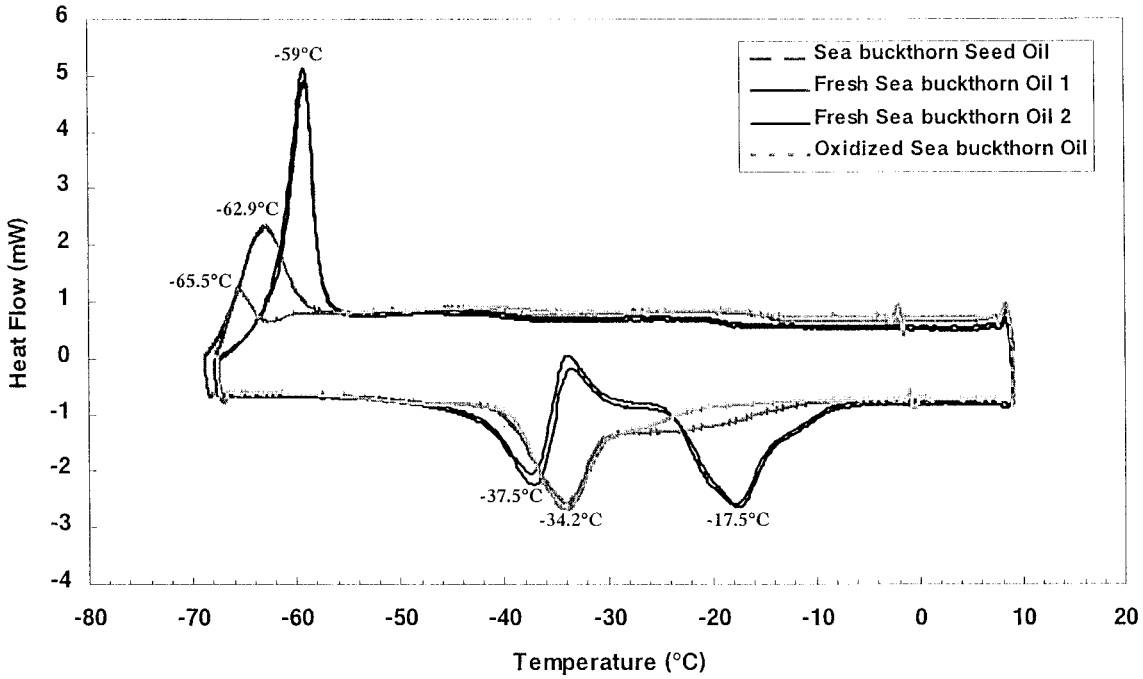

Figure 3. Differential scanning calorimetry (DSC) of sea buckthorn oil. Sea buckthorn seed oil represents a stored sample, and the oxidized sample has been purposely oxidized by bubbled air (see text).

of facial creams manufactured in Europe and Asia (Schroeder and Yao, 1995).

Sea buckthorn seed oil has unique melting and crystallizing characteristics (Figure 3). Fresh sea buckthorn seed oil crystallizes at −59 °C, a temperature much lower than those at which typical vegetable oils such as canola (−43 °C) and sunflower (−45 °C) oils crystallize. Two polymorphic forms, high melting and low melting, with endotherms at −17.5 and −37.5 °C, respectively, characterize the melting behavior. Storage and oxidation result in deterioration of the oil characterized by lowering of the crystallization temperatures toward the −62 to −65 °C range (Figure 3). A single melting point at ∼−34.2 °C was observed for oxidized sea buckthorn seed oil.

The fatty acid composition of sea buckthorn seed oil is characterized by high levels of unsaturated linoleic and linolenic acids (Table 6). These essential fatty acids are claimed to relieve chronic eczema, cure dermatitis, and maintain healthy skin (Oomah and Mazza, 1998). Furthermore, these fatty acids are claimed to alleviate clinical neurological symptoms as an anticancer agent (Oomah and Mazza, 1998), providing further health-promoting potential. The fatty acid profile together with the high content of carotenoids and tocopherols may be responsible for reported antimutagenic properties (Nerseian et al., 1990), therapeutic action on eye burns (Nikulin et al., 1992), stimulating effects on skin wound healing (Tanev et al., 1995), and prevention and treatment of peptic ulcer (Degtiareva et al., 1991). All of these various claims await independent confirmation but explain the potential use of the oil for cosmetic and pharmaceutical purposes.

Sea Buckthorn Leaves. Sea buckthorn leaves contain many nutrients and bioactive substances. It was reported that the flavonoid content in leaves ranges from 319 to 2100 mg/100 g of air-dried leaves (Chen et al., 1991). Goncharova and Glushenkova (1996) reported that sea buckthorn leaves were rich in carotenoids, free and esterified sterols, triterpenols, and isoprenols. Numerous products are made from sea buckthorn leaves such as leaf extract (Salenko et al., 1986), tea, tea powder, and animal feed.

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