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Review

Composition and physiological effects of sea buckthorn (*Hippophaë*) lipids

Baoru Yang* and Heikki Kallio

Department of Biochemistry and Food Chemistry, University of Turku, FIN-20014 Turku, Finland (Tel: +358-2-333-6843; fax: +358-2-333-6860.; e-mail: baoyan@utu.fi)

Sea buckthorn (*Hippophaë rhamnoides*) berry has a long history of application as a food and medicinal ingredient in eastern countries. Both seeds and the soft parts (fruit flesh and peel) of the berry are rich in lipids. The oils isolated from the two fractions differ in fatty acid composition and both are abundant in fat-soluble vitamins and plant sterols. The composition varies according to origin and harvesting time of the berries and the method of oil isolation. Results of clinical investigations and animal experiments suggest a wide range of positive effects of the oils. The composition, nutritional effects, and industrial application of sea buckthorn lipids are reviewed in this paper.

Sea buckthorn (genus *Hippophaë*) is a berry-bearing, hardy bush of the family *Elaeagnaceae*, naturally distributed in Asia and Europe (Rousi, 1971). It includes several species, of which *H. rhamnoides* is most important and is further divided into nine subspecies (Rousi, 1971). Figure 1 presents the natural distribution of sea buckthorn (Li & Shroeder, 1999; Rousi, 1971). Lian, Lu, Xue, and Chen (2000) classified subsp. *gyantsensis* as a separate species, *H. gyantsensis*. A new species, *H. goniocarpa* growing naturally in Sichuan and Qinghai provinces, China, has recently been described (Lian *et al.*, 2000).

Sea buckthorn is resistant to cold, drought, salt and alkali. The vigorous vegetative reproduction and the strong, complex root system with nitrogen-fixing nodules make sea buckthorn an optimal pioneer plant in soil and water conservation and reforestation of eroded areas.

Lipophilic components of sea buckthorn berries

Oil content

One special feature of sea buckthorn berry is the high oil content in the soft parts, in addition to oil in seeds. The oil content in seeds is commonly ~10%, although higher values (up to 15–16%) have been reported in some cultivars and wild berries from the Altai, Czech Republic and Tajikistan (Franke & Müller, 1983; Kallio, Yang, Peippo, Tahvonen, & Pan, 2002; Kallio, Yang, Tahvonen, & Hakala, 2000; Yang, 2001; Yang & Kallio, 2002). In contrast to the seeds, the oil contents in the fruit flesh and peel (the so called soft parts) and thus in the whole berries vary considerably with origins and other factors. In fresh berries, the oil level ranges from 1.4% in subsp. *sinensis* from China up to 13.7% in subsp. *turkestanica* from the Western Pamirs (Table 1) (Yang, 2001). Within a single population, the oil content in the berries correlates with morphological characteristics such as size and colour of the berries, which may lead to a difference of up to 2-fold (Yang, 2001). In addition, harvesting time influences oil content in the berries (Yang, 2001; Yang & Kallio, 2002).

Dried pulp/peel fraction of berries of subsp. *caucasica* (growing in the North Caucasus region and Gruziya) and subsp. *turkestanica* growing in Uzbekistan and China (Xinjiang) have the highest oil content (30–34% by petroleum extraction) (Table 1). The lowest oil content (4–12%, based on dry weight of the soft parts) is found in the wild berries of subsp. *sinensis* from Hebei Province, China (Yang, 2001).

Fatty acids

Sea buckthorn seed oil is rich in the two essential fatty acids, linoleic (18:2 n-6) and α-linolenic (18:3 n-3) acids. The proportions of the two fatty acids in seed oil are

* Corresponding author

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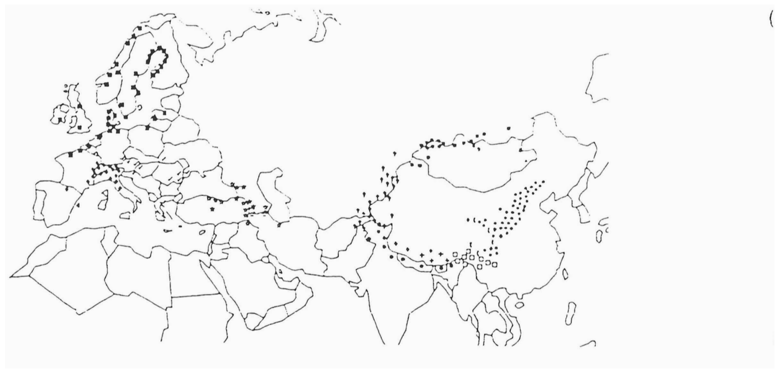

Fig. 1. The natural distribution of sea buckthorn in Europe and Asia (Li & Shroeder, 1999; Rousi, 1971).

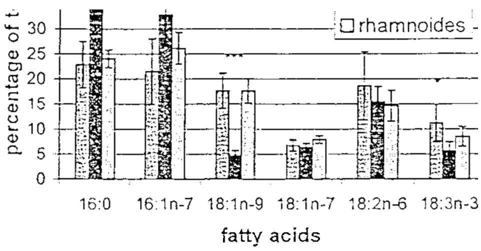

Fig. 2. Fatty acid composition of seeds (A) and the soft parts (B) of berries of three subspecies of sea buckthorn (Kallio *et al.*, 2002; Yang & Kallio, 2002). * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

Table 1. Oil content in soft parts and whole berries of different subspecies of *Hippophaë rhamnoides*

Subspecies	Fresh whole berries (%)	Dry soft parts (%)
caucasica	3–5	23–34
turkestanica	4–14	18–34
mongolica	2–10	16–28
carpatica	4–7	
rhamnoides	3–8	3–5 (fresh weight)
sinensis	2–3	4–20

commonly 30–40 and 20–35%, respectively. Other major fatty acids in seeds are oleic (18:1 n-9, 13–30%), palmitic (16:0, 15–20%), stearic (18:0, 2–5%), and vaccenic (18:1 n-7, 2–4%) acids (Franke & Müller, 1983; Kallio *et al.*, 2000, 2002; Yang, 2001; Yang & Kallio, 2002). In spite of the differences in some morphological characteristics and in growth conditions, subsp. *sinensis* (from China), *mongolica* (from Russia) and *rhamnoides* (from Finland) have almost identical fatty acid composition in seeds (Fig. 2a) (Kallio *et al.*, 2002; Yang, 2001; Yang & Kallio, 2002).

The soft parts of the berries have a fatty acid composition rather different from that of the seeds, characterized by the high level of palmitoleic (16:1 n-7, 16–54%), which is very uncommon in the plant kingdom. Other dominating fatty acids in the soft parts are palmitic (17–47%) and oleic (2–35%) acids (Franke & Müller, 1983; Kallio *et al.*, 2000, 2002; Yang, 2001; Yang & Kallio, 2002). As an example, Fig. 2b presents the high variation in fatty acid composition of the berries (i.e. the soft parts) among different subspecies (Yang & Kallio, 2001). The proportion of palmitoleic acid correlates negatively with that of oleic acid (Kallio *et al.*, 2002; Yang & Kallio, 2001). The highest level of palmitoleic acid (up to 54%), and the lowest level of oleic acid (as low as 2%) are found in subsp. *mongolica* (Kallio *et al.*, 2002).

Molecular weight distribution of seed triacylglycerols (TAGs) (Johansson, Laakso, & Kallio, 1997) and the fatty acids at primary and secondary positions of TAGs in seeds (Ozerinina, Berezhnaya, Eliseev, & Vereshchagin, 1987) and in the soft parts (Ozerinina, Berezhnaya, & Vereshchagin, 1997) as well as the changes during the developmental period (Berezhnaya, Ozerinina, Tsydendambaev, & Vereshchagin, 1997) have been investigated in some cultivars.

Genetic factors (i.e. differences between species and subspecies) play a primary role affecting the fatty acid composition (Yang & Kallio, 2002). In ripe berries, the fatty acid composition in the soft parts varies with harvesting time (Yang & Kallio, 2002). In berries of a specific origin, the fatty acid compositions of seeds and soft parts remain rather constant among different harvesting years (Yang & Kallio, 2002). The variation in the fatty acid composition, especially in the soft parts of the berries, provides a great potential for industrial application and plant breeding when seeking extreme sources of certain fatty acids.

Tocopherols and tocotrienols

Both the seeds and the soft parts are good sources of tocopherols. The total content of tocopherols and tocotrienols varies within the range 100–300 mg/kg in seeds

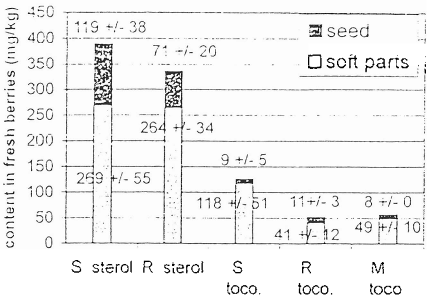

Fig. 3. The total content of sterols and tocopherols and tocotrienols in fresh berries of sea buckthorn of different subspecies (Kallio, Yang, & Peippo, in press; Kallio *et al.*, 2002; Yang, Carlsson *et al.*, 2001). S, *sinensis*; R, *rhamnoides*; M, *mongolica*; sterol, total sterols; toco., total of *tocopherols and tocotrienols*.

and 10–150 mg/kg in fresh berries (Kallio, Yang, & Peippo, in press; Kallio *et al.*, 2002; Yang, 2001). In the soft parts α-tocopherol alone constitutes up to 90% of the total tocopherols and tocotrienols while both α- and γ-isomers (each representing 30–50% of total) are the major ones in seeds. α-, β-, and γ-tocotrienols each consists of ~0.5–5% of total tocopherols and tocotrienols in soft parts, whereas in seeds the β-isomer (2–8%) clearly dominates accompanied by only trace amounts of α- and γ-isomers (Kallio *et al.*, in press; Kallio *et al.*, 2002; Yang, 2001). Among the three subspecies, *mongolica*, *rhamnoides* and *sinensis, sinensis* has the lowest total content of tocopherols and tocotrienols in seeds and the highest level in the fresh soft parts (Kallio *et al.*, in press; Kallio *et al.*, 2002). Figure 3 presents the content of tocopherols and tocotrienols in fresh berries of the three subspecies, showing the soft parts as the major source of these compounds (Kallio *et al.*, in press). In addition, it is clear from the figure that *sinensis* berries are more abundant in tocopherols than the berries of the other two subspecies. In seeds of ripe *sinensis* berries the total content of tocopherols and tocotrienols increases considerably during the harvesting period from the end of August to the end of November, resulting from increases in α- and γ-tocopherols, accompanied by a decrease in the corresponding values of the minor isomers (Kallio *et al.*, in press). The levels in the soft parts vary considerably with harvesting time but without a clear changing pattern (Kallio *et al.*, in press).

The level of tocopherols and tocotrienols in seed oil and whole berry oil is typically 0.1–0.3%. In addition to origin and harvesting time, methods of oil isolation influence the level of these compounds in the oils (Kallio *et al.*, in press; Kallio *et al.*, 2002; Yang, 2001).

Sterols

The sterol content is typically 0.1–0.2% in seeds and 0.02–0.04% in the soft parts (both based on fresh weight) (Yang, Carlsson, Oksman, & Kallio, 2001). In fresh berries of subsp. *sinensis* and *rhamnoides* the sterol content falls within the range of 350–500 mg/kg, of which 70–80% exists in the soft parts (Fig. 3) (Yang, Carlsson *et al.*, 2001). The two subspecies do not differ in the sterol content (Yang, Carlsson *et al.*, 2001). The levels in oils vary according to both raw materials and methods of oil isolation (Bat & Tannert, 1993; Xin *et al.*, 1997; Yang, Carlsson *et al.*, 2001). Typical values are 1–2% in seed oil and 1–3% in oil from the soft parts (Bat & Tannert, 1993; Xin *et al.*, 1997; Yang, Carlsson *et al.*, 2001). Sitosterol constitutes 60–70% of seed sterols and up to 80% of those in soft parts. Isofucosterol is another major sterol representing 10–20% of seed sterols and 2–5% of sterols of the soft parts. Campesterol, stigmastanol, citrostadienol, avenasterol, cycloartenol, 24-methylenecycloartanol, obtusifoliol, each represents 1–5% of total sterols of both fractions (Bat & Tannert, 1993; Xin, Li, Wu, & Aitzmüller, 1997; Yang, Carlsson *et al.*, 2001).

The total sterol content and the content of sitosterol in seeds of subsp. *sinensis* remain rather constant from the end of August to the end of November (Yang, Carlsson *et al.*, 2001). A clear increase in campesterol and a decrease in stigmastanol are found in seeds. During the same period, a common increase is found in the levels of the compounds in the earlier part of the major pathway, accompained by a decrease in the compounds in the later part, including a decrease in sitosterol (Yang, Carlsson *et al.*, 2001). Free sterols and steryl esters differ in the relative proportions of individual compounds; specifically, the free sterol fraction contains a higher proportion of sitosterol accompanied by lower proportion of cycloartenol and 24-methylenecycloartanol, two compounds in the early part of the biosynthetic pathway (Fig. 4) (Yang, Kallio, Koponen, & Tahvonen, 2001).

Carotenoids

Carotenoids mainly exist in the soft parts, giving the berries their beautiful yellow-orange colour. The concentration in seeds is typically 1/20–1/5 of that in soft parts (Yang, 2001). β-Carotene consitutes 15–55% of total carotenoids, depending on the origin (Yang, 2001). Even though α-carotene, γ-carotene, dihydroxy-β-carotene, lycopene, zeaxanthin and canthaxanthin have been reported to be the other carotenoids in sea buckthorn berries (Kallio, Malm, Kahala, & Oksman, 1989; Yang, 2001), much work remains to be done on the identification and biochemistry of carotenoids in the berries. The content of carotenoids in the berries are subject to extreme variation; differences up to 10-fold has been reported even within the same natural population and subspecies. Levels of β-carotene from 0.2 to 17 mg/100 g and total carotenoids (calculated as β-carotene) from 1 to 120 mg/100 g in fresh berries have been reported in the literature (Yang, 2001).

Both raw material and methods of oil isolation influence the content of catotenoids in the oils.

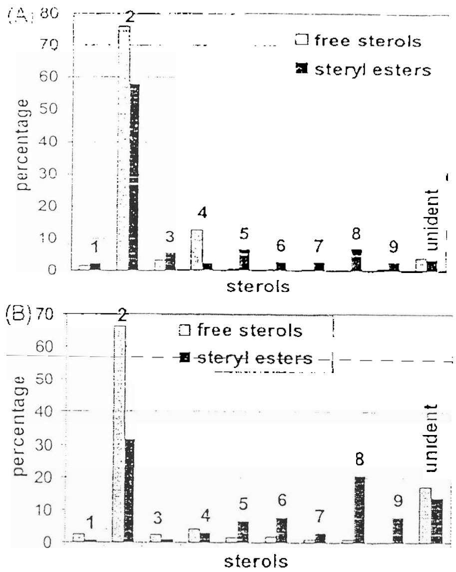

Fig. 4. The sterol composition (weight percentage) in free sterols and steryl esters in seeds (A) and the soft parts (B) of sea buckthorn berries of subsp. *sinensis* (Yang, Kallio *et al.*, 2001). 1, Campesterol; 2, sitosterol; 3, stigmastanol; 4, isofucosterol + obtusifoliol; 5, cycloartenol + stigmast-7-en-ol; 6, 4,14-dimethyl-9,19-cyclo-ergost-24(24[1])-en-ol; 7, stigmasta-7,24-dien-ol; 8, 24-methylenecycloartanol; 9, citrastadienol; unidenti., total of unidentified sterols

Common levels of β-carotene are 100–500 mg/100 g in pulp oil and 20–100 mg/100 g in seed oil (Yang, 2001).

Physiological effects of sea buckthorn oils

Sea buckthorn berries have a long history of application in Tibetan and Mongolian medicines for treating sputum and cough, and for improving blood circulation and the function of the digestive system (Ge, Shi, Zhang, & Wang, 1985). Since 1977, the berry has been a medicinal ingredient listed in the Chinese Pharmacopeia. During the second half of the twentieth century, numerous animal experiments and clinical studies have been carried out to investigate the physiological effects of sea buckthorn oils. Most of these publications are written in Chinese and Russian; many are case reports rather than scientific investigations. An extensive review and analysis of these papers has been made elsewhere (Yang, 2001). Figure 5 presents an overview of the claimed effects of the oils supported by scientifically sound experimental results. Some of the claims have been proved by the latest studies carried out in Europe

Antioxidative effects

Oils from seeds and soft parts of sea buckthorn berries have been shown to slow down the oxidation process and to stabilize membrane structure in animal models (Ji & Gao, 1991; Rui & Gao, 1989). An eight-

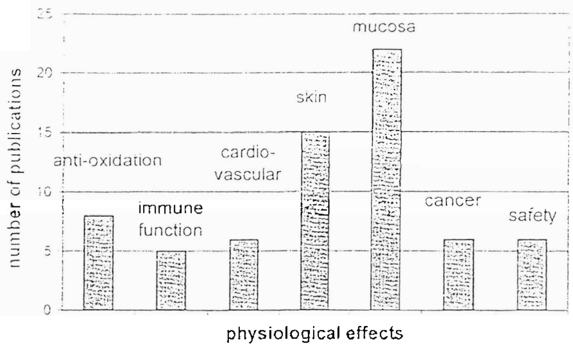

Fig. 5. Publications on the physiological effect of sea buckthorn oils (Yang, 2001).

week feed supplementation with sea buckthorn seed oil decreased the malondialdehyde (MDA) levels in erythrocyte membrane and in the liver of rats (Ji & Gao, 1991). Incorporation of the pulp oil into the feed of rats (Song & Gao, 1995) and guinea pigs (Rui & Gao, 1989) suppressed the membrane MDA levels of erythorcytes and protected the animals from cold-induced tissue damage. The oil supplementation increased the activities of glutathione peroxidase (GSH-Px) (Ji & Gao, 1991; Song & Gao, 1995), Na,K-ATPase (Rui & Gao, 1989), superoxide dismutase (SOD) (Song & Gao, 1989), and glucose-6-phosphate dehydrase (G-6-PD) (Rui & Gao, 1989) as well as the membrane levels of sialic acid and the sulfydryl group (Ji & Gao, 1989) in the erythrocytes.

Intragastrically given seed oil (Cheng, Pu, Ma, Cao, & Li, 1994) and pulp oil (Cheng, Li, Duan, Cao, Ma, & Zhang, 1990) protected against chemically induced liver damage in animal models. In addition, the oil treatments suppressed the level of MDA, maintained the normal activity of serum glutamic pyruvic transaminase (SGPT) and serum glutamic oxaloacetic transaminase (SGOT), and increased the activity of SOD and GSH-Px in liver (Cheng *et al.*, 1990, 1994).

Effects on skin and mucosa

Topically applied sea buckthorn oils promoted the healing of wounds (Mironov *et al.*, 1983), burns (Lebedeva, Akmolova, Haydarov, & Ismailova, 1992), and irradiation dermatitis (Zhang *et al.*, 1988) in skin. Tissue-regenerative, anti-inflammatory and anti-microbial effects of the oils are among the mechanisms related to the effects observed (Kallio *et al.*, 2001; Lebedeva *et al.*, 1992; Zhang *et al.*, 1988). Both sterols (Lebedeva *et al.*, 1992) and long chain alcohols (Kallio *et al.*, 2001) have been reported to be the active components responsible for these effects.

Dietary supplementation with supercritical-CO_2-extracted seed and soft part oils improved the symptoms of atopic dermatitis (AD) (Yang *et al.*, 1999). The seed

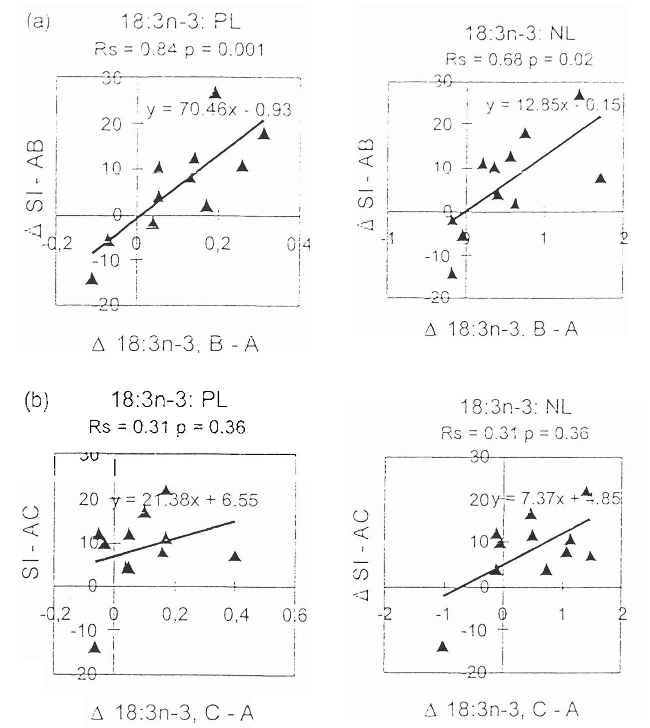

Fig. 6. Correlation between symptom improvement and increase in proportion of α-linolenic acid (Δ 18:3n-3) in plasma lipids in sea buckthorn seed oil group (a) after 1 month (Δ SI-AB) and (b) after 4 months of administration (Δ SI-AC). PL, phospholipids; NL, neutral lipids; A, before treatment; B, after 1 month of treatment; C, after 4 months of treatment (from Yang et al., 1999) (©1999, with permission from Elsevier Science).

oil increased the proportion of linoleic, α-linolenic, and eicosapentaenoic (20:5 n-3) acids in plasma lipids (Yang *et al.*, 1999). The increase in α-linolenic acid correlated positively with the improvement of AD symptoms (Fig. 6), suggesting positive effects of the fatty acid (Yang *et al.*, 1999). The effects may be related to a competitive inhibition of the synthesis of the 4-series leukotrienes from arachidonic acid by an increased synthesis of the 5-series leukotrienes. The soft part oil increased the proportion of palmitoleic acid in plasma phospholipids and neutral lipids. However, the changes in palmitoleic acid did not correlate with symptom improvements (Yang *et al.*, 1999). The effects of the two oils may be related to different mechanisms. The oil supplementation did not lead to significant changes in the skin glycerophospholipids of AD patients (Yang, Kalimo, Tahvonen, Mattila, Katajisto, & Kallio, 2000).

Both animal and clinical studies have shown protective and curative effects of sea buckthorn oils on mucosa membrane against various damages. The results of experiments using animal models of gastric ulcer (Che, Huo, Zhao, Feng, & Zhang, 1998; Mironov *et al.*, 1989) have strongly supported the clinical success of treating and preventing ulcers in oral and gastro-duodenal mucous membrane (Qiu & Qiao, 1997). Oil from the soft parts is reported to be more effective than seed oil (Mironov *et al.*, 1989). Several studies suggest sterols and steryl glycosides to be the major anti-ulcer compounds in the oils (Jiang & Li, 1987; Romero & Lichtenberger, 1990). Sea buckthorn oils have been used successfully in treating chronic cervicitis (Wu *et al.*, 1992).

Effects on risk factors of cardiovascular diseases

Results of animal experiments and clinical trials suggest that eating sea buckthorn oils may lower the risk for cardiovascular disease. This includes decreasing the plasma total and LDL-cholesterol levels (Jiang *et al.*, 1993), increasing the level of HDL-cholesterol (Ecclestone, Yang, Tahvonen, Kallio, Rimbach, & Minihane, 2002; Jiang *et al.*, 1993; Yang *et al.*, 1999), inhibiting thrombus formation and atherosclerosis (Johansson, Korte, Yang, Stanley, & Kallio, 2000; Xu & Chen, 1991) and retarding oxidation of LDL (Ecclestone *et al.*, 2002; Wang, Lu, Liu, Guo, & Hu, 1992).

In a small-scale cross-over study conducted with supercritical CO_2-extracted sea buckthorn berry oil (Johansson *et al.*, 2000), 12 healthy men took 5 g oil per day for a period of 4 weeks. The oil supplementation reduced the adenosine-5′-diphosphate-induced platelet aggregation reaction rate ($P<0.05$) and the maximum aggregation (aggregation percentage at 4 min, $P<0.01$), compared with fractionated coconut oil (Fig. 7). Taking oil-containing sea buckthorn juice for a period of 8 weeks decreased the suscepibility of LDL to oxidation and increased HDL-cholesterol level in plasma of healthy men (Ecclestone *et al.*, 2002).

Effects on immune function

Effects of sea buckthorn seed oil on immune functions have been investigated mostly with experimental models in mice. Intraperitoneal injection of sea buckthorn seed oil improved the immune functions of normal mice (Wang *et al.*, 1989). Intragastrically given seed oil showed antagonistic effects against cyclophosphamide-induced immune suppression in mice (Ren, Yang, Zhang, Zhong, & Su, 1992). Sea buckthorn seed oil was effective as an adjuvant treatment for improving the immune function of cancer patients receiving chemotherapy (Li & Tan, 1993). In several experiments, sea buckthorn juice improved immune function of mice. It is possible that both the oil fraction and the water-soluble components (flavonoids, vitamin C, and lignans) have contributed to the effects.

Anti-cancer effects and safety aspects

Intraperitoneal injection of sea buckthorn seed oil has been reported to suppress the growth of S180 and B16 tumours in mice (Zhang, Ding, Mao, Li, & Li, 1989). Intraperitoneal injection of oil from sea buckthorn press residue elongated dose-responsively the living period of mice pre-inoculated with S180 cells (Yang *et al.*, 1989).

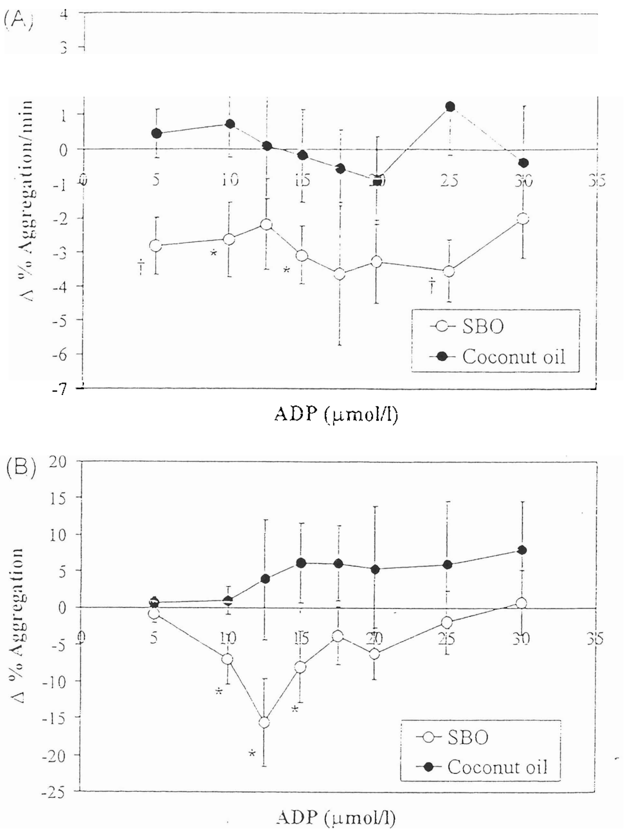

Fig. 7. Δ-Values (value after−value before supplementation) of the adenosine-5′-diphosphate-induced platelet aggregation: (A) difference in the rate of aggregation reaction (Δ% aggregation/min); (B) difference in the maximum aggregation (Δ% aggregation) at 4 min. Results are mean±SEM of 11 subjects. Δ-values in sea buckthorn berry oil and fractionated coconut oil supplementation groups differ significantly at *$P<0.05$ or †$P<0.01$. [from Johansson *et al.* (2000) Copyright (2000), with permission from Elsevier Science]

In vitro study also suggested a cytotoxic effect of the oil on human leukemia cell line K562 (Yang *et al.*, 1989). *In vivo* animal studies suggested that sea buckthorn oil *per os* alleviated the hematological damage caused by chemotherapy (Abartiene & Malakhovskis, 1975).

Sea buckthorn as an edible berry has a long history of application as a food both in Asia and in Europe. Both seed oil and oil from the fruit soft parts have been proved to be safe by toxicological studies using animal models. The investigations include acute and chronic toxicity on blood, liver and heart as well as mutagenicity and teratogenicity of ingested oils. These studies have been reviewed (Yang, 2001).

Production and application of sea buckthorn oils: the present and the future

In China and Russia, sea buckthorn oils have been used as raw materials of health products (nutraceuticals and natural medicines) and cosmetics for a few decades. Recently, sea buckthorn oils are becoming more and more popular as special food supplements and ingredients in Japan, Europe and North America as a result of the increasing information on the nutritional effects of the oils in the western countries.

Pressing is not a suitable method for isolating oil from the seeds due to low yield and the high price of the raw material, although centrifugation and decanting are efficient methods for separating oil from the juice fraction. The conventional method for oil isolation from seeds and dried press residue is solvent extraction using hexane or freon, of which a main drawback is solvent residue in the oil in addition to environmental pollution. Other vegetable oils, such as sunflower seed oil and rapeseed oil sometimes are used to extract oil from sea buckthorn seeds, yielding oils with mixed composition. Supercritical CO_2 extraction (CO_2-SFE) as a new, organic-solvent-free technology is replacing the conventional solvent extraction methods. If the process is optimized, aseptic oil with sufficient yield can be obtained (Manninen, Häivälä, & Kallio, 1996). The oil composition can be adjusted by a careful selection of the parameters of the extraction process.

As a result of both the expensive raw material and the high production cost of SFE process, CO_2-SFE sea buckthorn oils are avaible at a price range of 100–200 €/kg, seed oil being more expensive than the pulp oil. Instead of as common food ingredients, the oils are mainly marketed as food supplements as gelatine or vegetable-based capsules and oral liquid. These products are targeted especially for maintaining the health of skin, mucosa, cardiovascular and immune system.

For large scale food application, continuous availability of the raw material at a reasonble price and considerable reduction of the extraction cost of SFE process are the prerequisites. China has up to 90% of world's sea buckthorn resource of 1.4 million ha. The average yield is about 200 kg/ha. The world's annual yield of sea buckthorn berries should add up to 28,000 tons. The Ministry of Water Resources of China is launching a ecological program including large scale planting of sea buckthorn in Northern China. This will further increase the supply of the berries in a few years. Active research programs of plant breeding and selection for varieties with higher yield and better qualities of berries are in progress in the country. In Russia selection and cultivation of sea buckthorn have been carried out for a few decades. Largely in response to growing industrial utilization, the plantation and cultivation of sea buckthorn have seen a rapid increase in European countries during the past few years. Efficient harvesting methods should be developed to cope with the increasing yield of the berries, especially in the countries with high cost of labour. A well-coordinated internaional collaboration network is necessary to make the best use of exisiting sea buckthorn resources and to supply raw materials at a considrably reduced price especially in Europe and North America.

Incorporating the oils into daily foodstuffs, such as bread, juice and yoghurts, represents a new trend in the application of sea buckthorn oil. The high content of polyunsaturated fatty acids and other oxygen-sensitive lipid nutrients such as carotenoids and tocopherols make the oil susceptible to oxidation, which limits the application of the oils. Microencapsulation converts the oil into powder form and protects the oil from oxidation, especially when combined with addition of antioxidants (Partanen, Yoshii, Kallio, Yang, & Forssell, 2002). This will increase the stability of the oil and improve the shelf life and sensory properties of oil-incorporated products. Both the encapsulating material and the parameters of the process should be carefully optimized to obtain sufficient stability of the capsules and high absorption efficiency of the encapsulated oil in the human intestine. The latter should be tested with well-designed clinical investigations using specific oil-incorporated products and monitoring a number of biomarkers clearly defined for the purpose of the study. Further clinical investigation on the health effects of the oils and oil-containg food products are needed to prove the existing claims and to explore new prospects of the oils as a potential ingredient of funtional foods.

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