Sea Cucumber *(Cucumis marimus):* Nutritional Composition and Potential Health Benefits

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The ocean is a promising source of novel bioactive nutraceuticals; however, the development of marine-derived nutraceuticals is still in its infancy. The discovery of nutraceuticals such as omega-3 polyunsaturated fatty acids have attracted many researchers to discover bioactive natural ingredients from marine sources. Sea cucumber has been consumed as food and as a dietary supplement in Asian traditional medicine. Recent studies revealed that sea cucumber is rich in bioactive compounds and possesses potential health benefits against chronic diseases, especially antioxidant and lipid-lowering properties. A literature search suggests that the nutritional composition of sea cucumber obtained from different regions varies dramatically, which influences its health potential.

Introduction

Many researchers have explored marine natural products for the isolation of beneficial therapeutic agents. There are about 16,000 natural products that have been isolated from marine organisms that possess a robust biological activity. Marine organisms not only provide pharmaceutically beneficial compounds but are also used as functional foods and nutraceuticals worldwide. Marine organisms are novel sources of biologically active compounds such as bioactive peptides, antimicrobials, and anticancer agents. Among marine products, sea cucumber (SC) has recently gained attention as a value-added product, especially in Asian countries, and is commercially harvested in China and Malaysia. The commercial species are also found in Canada's North Atlantic and North Pacific regions and the Pacific coast of California, Oregon, Washington, and Alaska. The consumer market for SC is large in Asian countries such as China, Hong Kong, Japan, South Korea, Malaysia, and Singapore, although there is a small ethnic market in the U.S. and Canada.

Sea cucumber is an echinoderm, including starfish and sea urchins, with a leathery skin body, looking like a cucumber. Echinoderms, including holothurian SC, are most abundant on the abyssal seafloor. Most of the echinoderms are deposit feeders; the holothurian SC feeds passively on phytoplankton and organic detrital material from the seafloor. Traditionally, SC was consumed as a food and a dietary supplement in Asian traditional medicine for its curative properties. SC tonic has been used as a traditional remedy against hypertension, asthma, rheumatism, and constipation. Several scientific studies support this bioactive food's traditional medicinal claim as wound healing promoters and exhibiting antimicrobial, antiangiogenic, anticancer, anticoagulant, and possessing immunomodulatory properties. The medicinal properties of SC are attributed to the presence of saponins, fucosylated chondroitin sulphates, fucoidan, sulphated polysaccharides, sterols, phenolics, and peptides. Furthermore, SC is a rich source of protein and omega (n)-3 polyunsaturated fatty acids (PUFA), especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Although SC has been associated with several health benefits, the literature suggests that the composition of SC from different parts of the world varies dramatically, which may affect the health benefits of SC.

Sea Cucumber: Taxonomy and Distribution

Sea cucumber is scientifically known as *Cucumis marimus*. The local or common names of SC are holothuroid, holothurians, timun laut, bat, balat, brunok, gamat, and hoi sum. SC is a soft and cylindrical-bodied echinoderm that dwells in the abyssal seafloor and feeds on the phytoplankton debris of the seafloor. There are about 1,400 to 2,000 reported species of SC, belonging to 25 families, with six orders, and there are approximately 20 edible SC reported so far. SC belongs to phylum Echinodermata and class Holothuroidea, with three subclasses *viz*. Dendrochirotacea, Aspidochirotacea, and Apodacea, and six orders: Aspidochirotida (340 species in 35 genera and three families), Apodida (269 species in 32 genera and three families), Dactylochirotida (35 species in seven genera and three families), Dendrochirotida (550 species in 90 genera and seven families), Elasipodida (141 species in 24 genera and five families), and Molpadiida (95 species in 11 genera and four families). The edible species of SC belong to two families of the Aspidochirotids, with seven genera and one family and genus of the Dendrochirotids.

The identification of SC species is essential for commercial utilization in order to avoid adulteration. SC is generally identified based on its morphological characteristics, *viz*. the number of tentacles, the nature of internal respiratory trees, trunk podia, and esophageal calcareous rings. The number of oral tentacles is SC's most prominent identification criteria to differentiate them for subclass types; for example, the oral tentacles of Dendrochirotacea are from eight to 30, whereas Aspidochirotacea possesses 10-30 oral tentacles, and Apodacea contains up to 25 oral tentacles. SC grows up to 10-30 cm in length. Apart from the tentacles, the habitat and behaviour characteristics of SC have also been considered important in its classification. Alternative to traditional identification, the chemical composition of SC, *viz*. chemo-taxonomy has been utilized in recent years, primarily based on the presence or distribution of triterpene glycosides in different species of SC. A combination of traditional identification and chemo-taxonomy is highly effective in identifying the taxonomy of fresh and whole SC. However, this approach is ineffective for commercially processed SC, where the purification of species-specific chemical components, *viz*. triterpene glycosides, is complicated and often inaccurate. In order to avoid the difficulties of species identification, researchers have used DNA fingerprint analysis by utilizing rapid analysis of polymorphic DNA and restriction fragment length polymorphism. However, only five species have been identified using DNA fingerprint analysis, *viz*. *Apostichopus japonicus, Cucumaria frondosa, Thelenota ananas, Parastichopus californicus,* and *Actinopyga lecanora* collected from Qingdao, China. Thus, there is a need to characterize and identify other species of SC to establish their region specificity and nutritional composition.

Nutritional and Chemical Composition of SC

Traditional and modern medicine recommends the consumption of SC as a dried product known as *bêche-de-mer*, and also referred to as "tapang" or "hai-som" in Indonesia and China. SC is consumed as raw, pickled, or fried food in Japan and Korea rather than dietary supplementation of dried products. SC is available in the commercial market as a dried product worldwide. The dried SC can be graded into low, medium, or high economic value products depending on the species, appearance, abundance, colour, odour, and thickness of the body wall.

Proximate Composition of SC

The proximate composition of SC varies markedly depending on the species, habit, and habitat. The proximate composition of different species of SC collected from different localities is in the range of 4.76 to 94% moisture, 2 to 32.7% ash, 0.9 to 48.6% carbohydrate, 0.09 to 29% fat/lipid, and 8.34 to 58% protein (Table 1A-1E). Generally, the moisture content of different species of SC collected from different localities does not show a significant variation. However, the moisture content of red giant SC (*Parastichopus californicus*) collected from Uyak Bay and Kodiak Island, Alaska, U.S., was lower in the body wall (4.03%) and muscle band (5.50%) compared to other species of SC. The moisture content of *Stichopus chloronotus* (Figure 1) and *Bahadaschia argus* from the Nhachang Inlet of South Vietnam was higher (94.1 and 91.4%, respectively) compared to other species (Table 1A). SC's ash, carbohydrate, lipid, and protein content also varies greatly, and depends on the species, habitat, and even different body parts (Table 1B-1E). The SC species, *H. parva*, has been reported to have higher ash content (32.74%) compared to other species. In contrast, the ash content of *Actinopyga mauritiana* from the Red Sea of the Egyptian coast and *Cucumaria frondosa* from Newfoundland and Labrador (N.L.) were reported to be low (2.12 and 2.97%, respectively) (Table 1B). The carbohydrate content of SC was relatively high in all species collected from the Egyptian

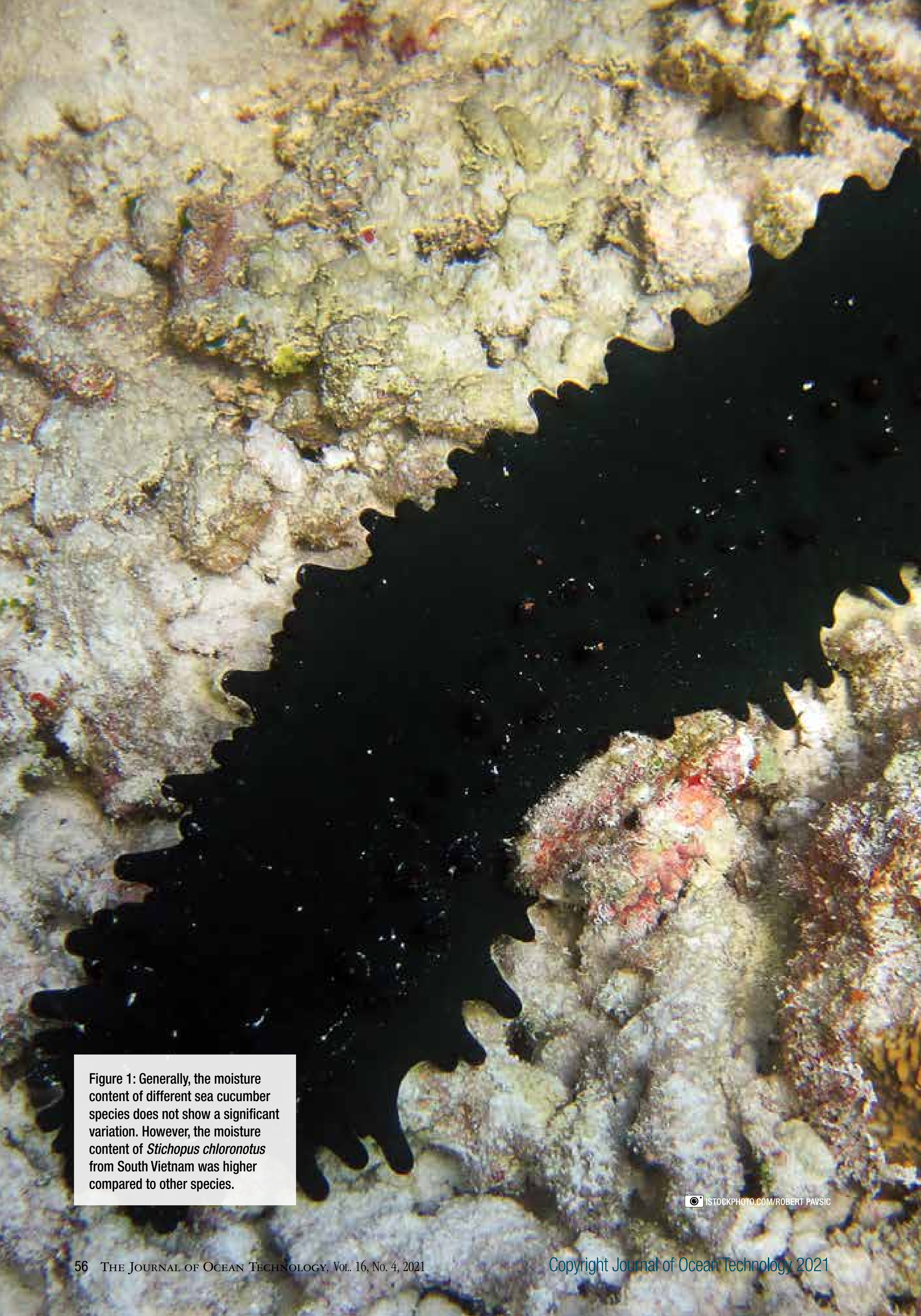
Figure 1: Generally, the moisture content of different sea cucumber species does not show a significant variation. However, the moisture content of *Stichopus chloronotus* from South Vietnam was higher compared to other species.

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Component	Species / Variety	Habitat	Concentration (Units)
Moisture	*Holonthuria leucospilota*	Nhachang Inlet (Southern Vietnam)	89.4(%)
	H. atra		87.0(%)
	H. impatiens		83.1(%)
	H. pardalis		85.5(%)
	H. moebil		86.8(%)
	Pearsonothuria graeffei		89.3(%)
	Bahadschia argus		91.4(%)
	Stichopus chloronotus		94.1(%)
	Euapta godeffroyi		84.2(%)
	Cucumaria frondosa	Newfoundland, Canada	87.4(%)
	H. polii	Bndar-e-lengeh coast (South of Iran)	81.2(%)
	H. tubulosa		84.3(%)
	H. mammata		85.2(%)
	Parastichopus californicus	Uyak Bay; Kodiak Island Alaska, U.S.	4.76(%)
	H. parva	Bndar-e-lengeh coast (South of Iran)	67.9(%)
	H. arenicola		69.5(%)
	Actinopyga mauritiana	Red Sea (Egyptian Coast)	84.7(%)
	H. scarba		85.8(%)
	H. leucospilota		83.2(%)
	Bohadschia marmorata		81.4(%)

Table 1A: Moisture content of sea cucumber.

Information included in Table 1A-E was sourced as follows:

Aydin, M.; Sevgili, H.; Tufan, B.; Emre, Y.; and Kose, S. [2011]. *Proximate composition and fatty acid profile of three different fresh and dried commercial sea cucumbers from Turkey*. https://www.researchgate.net/profile/Mehmet-Aydin-12/publication/230120639_Proximate_composition_and_fatty_acid_profile_of_three_different_fresh_and_dried_commercial_sea_cucumbers_from_Turkey/links/5a40ecd10f7e9ba8689ee8a3/Proximate-composition-and-fatty-acid-profile-of-three-different-fresh-and-dried-commercial-sea-cucumbers-from-Turkey.pdf.

Bechtel, P.J.; Oliveira, A.C.M.; Demir, N.; and Smiley, S. [2013]. *Chemical composition of the giant red sea cucumber, Parastichopus californicus, commercially harvested in Alaska*. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3951569/.

Omran N.E.S.E.S. [2013]. *Nutritional value of some Egyptian sea cucumbers*. https://academicjournals.org/journal/AJB/article-full-text-pdf/A1BC3BC30098.

Salarzadeh, A.R.; Afkhami, M.; Bastami, K.D.; Ehsanpour, M.; Khazaali, A.; and Mokhleci, A. [2012]. *Proximate composition of two sea cucumber species Holothuria pavra and Holothuria arenicola in Persian Gulf*. https://www.scholarsresearchlibrary.com/articles/proximate-composition-of-two-sea-cucumber-species-holothuria-pavra-and-holothuria-arenicola-in-persian-gulf.pdf.

Svetashev, V.I.; Levin, V.S.; Lam, C.N.; and Nga, D.T. [1991]. *Lipid and fatty acid composition of Holothurians from tropical and temperate waters*. https://www.sciencedirect.com/science/article/pii/0305049191902426.

Zhong, Y.; Khan, M.A.; and Shahidi, F.C. [2007]. Compositional characteristics and antioxidant properties of fresh and processed sea cucumber (*Cucumaria frondosa*). https://pubs.acs.org/doi/10.1021/jf063085h.

Component	Species / Variety	Habitat	Concentration (Units)
Ash	*C. frondosa*	Newfoundland, Canada	2.97(%)
	H. polii	Bndar-e-lengeh coast (South of Iran)	7.85(%)
	H. tubulosa		5.13(%)
	H. mammata		5.13(%)
	P. californicus	Uyak Bay; Kodiak Island, Alaska, U.S.	18.9(%)
	H. parva	Bndar-e-lengeh coast (South of Iran)	32.74(%)
	H. arenicola		10.86(%)
	A. mauritiana	Red Sea (Egyptian Coast)	2.12(%)
	H. scarba		2.26(%)
	H. leucospilota		4.3(%)
	B. marmorata		6.03(%)

Table 1B: Ash content of sea cucumber.

Component	Species / Variety	Habitat	Concentration (Units)
Carbohydrate	*C. frondosa*	Newfoundland, Canada	0.94(%)
	P. californicus	Uyak Bay; Kodiak Island, Alaska, U.S.	11.82(%)
	H. parva	Bndar-e-lengeh coast (South of Iran)	1.87(%)
	H. arenicola		2.3(%)
	A. mauritiana	Red Sea (Egyptian Coast)	44.62(%)
	H. scarba		48.65(%)
	H. leucospilota		44.96(%)
	B. marmorata		45.91(%)

Table 1C: Carbohydrate content of sea cucumber.

Component	Species / Variety	Habitat	Concentration (Units)
Lipid / Fat	*H. leucospilota*	Nhachang Inlet (Southern Vietnam)	12.6(%)
	H. atra		14.5(%)
	H. impatiens		19.2(%)
	H. pardalis		26.6(%)
	H. moebil		12.5(%)
	A. lecanora		29.0(%)
	P. graeffei		13.8(%)
	B. argus		16.1(%)
	S. chloronotus		21.8(%)
	E. godeffroyi		22.1(%)
	C. frondosa	Newfoundland, Canada	0.50(%)
	H. polii	Bndar-e-lengeh coast (South of Iran)	0.15(%)
	H. tubulosa		0.18(%)
	H. mammata		0.09(%)
	P. californicus	Uyak Bay, Alaska, U.S.	6.75(%)
	H. parva	Bndar-e-lengeh coast (South of Iran)	2.43(%)
	H. arenicola		2.88(%)
	A. mauritiana	Red Sea (Egyptian Coast)	4.99(%)
	H. scarba		5.66(%)
	H. leucospilota		4.60(%)
	B. marmorata		4.83(%)

Table 1D: Lipid content of sea cucumber.

coast (44-49%) compared to species collected from N.L. (0.94%), the coast of southern Iran (1.8-2.3%), and species from Alaska, U.S. (11.82%) (Table 1C). The lipid content was reported to be higher in all species collected from Nhachang Inlet of Southern Vietnam (12.5-29%), whereas the species collected from the coast of southern Iran (0.09-2.88%), Egyptian coast (4.8-5.6%), and N.L. (0.5%) have a lower content (Table 1D). The protein content of *P. californicus* from Alaska was found to be higher (57.72%) compared to other species. In comparison, the protein content was low in *H. mammata* (7.88%) from Iran and in *C. frondosa* (8.34%) from N.L. (Table 1E).

The amino acid content of SC also markedly differs among species collected from different localities (Table 2). Interestingly, almost all species reported so far showed a high content of glycine, glutamic acid, aspartic acid, and arginine compared to other amino acids. The ratio of total essential amino acids to total non-essential fatty acids, which reflects protein quality, is high in SC. The lysine to arginine ratio of the amino acid content of SC is significantly lower than other seafood products due to a considerable amount of threonine, tyrosine, and phenylalanine. These reports strongly demonstrate that the composition of SC varies among species and from region to

Component	Species / Variety	Habitat	Concentration (Units)
Protein	*C. frondosa*	Newfoundland, Canada	8.34(%)
	H. polii	Bndar-e-lengeh coast (South of Iran)	8.66(%)
	H. tubulosa		8.82(%)
	H. mammata		7.88(%)
	P. californicus	Uyak Bay; Kodiak Island, Alaska, U.S.	57.72(%)
	H. parva	Bndar-e-lengeh coast (South of Iran)	17.61(%)
	H. arenicola		24.37(%)
	A. mauritiana	Red Sea (Egyptian Coast)	48.27(%)
	H. scarba		43.43(%)
	H. leucospilota		45.71(%)
	B. marmorata		43.23(%)

Table 1E: Protein content of sea cucumber.

region; thus, it is certain that the health benefits of these species will vary.

Lipid Composition of SC

SC is a natural rich source of bioactive lipids; the fatty acids found in SC are the key components responsible for tissue repair and wound healing properties. It is well known that seafloor sediments contain a high level of branched-chain fatty acids. The holothurian SC dwell in the abyssal seafloor and feed on algae; they are enriched in bioactive branched-chain fatty acids. The content of saturated fatty acids, monounsaturated fatty acids (MUFA), and PUFA varies markedly among various SC species, and in different body parts of the same species. The variation in the fatty acid composition depends on the habitat of SC, the climatic region, and specific body parts. The predominant fatty acids in SC are myristic acid (14:0; 1.13-37.0%), arachidonic acid (ARA) (20:4 n-6; 0.73-42.4%), palmitic acid (16:0; 2.2-52.6%), and EPA (20:5 n-3; 0.17-56.7%), with lower levels of alpha-linolenic acid (18:3; 0.27-1.74%), arachidic acid (20:0; 0.5-7.5%), and DHA (22:6; 0.32-8.93%) (Table 3). Previously researchers have investigated the fatty acid profiles of the body wall and muscle bands of Giant Red SC. In *P. californicus*, the marked differences are primarily between the fatty acid profile of the body wall and the muscle band. MUFA are the most abundant class of fatty acids in the body wall (39.80% in body wall vs. 32.05% in muscle band), while PUFA is the predominant fatty acid in the muscle band (43.64% in muscle band vs. 28.88% in body wall). The most abundant MUFA in both tissues is palmitoleic acid (16:1 n-7) with 8.57% in muscle band and 14.99% in body wall. We have recently reported high levels of MUFA, especially 16:1 n-7 (17.45%) in SC (gut) from the cold waters of the province of N.L. in Canada.

The most prominent PUFA found in almost all species of SC are EPA and ARA. We have recently reported high levels of EPA (25.35% of total lipids) in SC found in the Great Northern Peninsula of the Canadian province of N.L. We also found that the n-3 PUFA were structured in the phospholipid form, well known for higher biological activity

Component	Content (g/100 g)
Alanine	3 – 6.5
Arginine	0.98 – 13.0
Aspartic acid	3.4 – 11.8
Glutamic acid	4.9 – 16.1
Glycine	4.8 – 19.1
Histidine	0.2 – 2.1
Isoleucine	0.43 – 4.2
Leucine	1.57 – 7.6
Lysine	0.73 – 7.6
Methionine	0.19 – 2.3
Phenylalanine	0.74 – 4.1
Proline	0.14 – 6.7
Serine	1.4 – 5.1
Theronine	0.36 – 5.7
Tyrosine	0.33 – 3.5
Valine	1.3 – 5.3
Total Amino Acid (TAA)	33.3 – 54.1
TEAA/TNEAA[1]	0.25 – 0.60
LYS/ARG[2]	0.13 – 3.6

[1]TEAA/TNEAA – Ration of total essential amino acids to total non-essential amino acids; [2]LYS/ARG – Lysine to arginine ratio.

Table 2: Amino acid composition of sea cucumber.

Fatty acids	Levels (%)
Caproic 6:0	-
Caprylic 8:0	0.03 – 0.07
Capric 10:0	0.04 – 0.08
Lauric 12:0	0.02 – 0.96
Myristic 14:0	1.13 – 37.0
Palmitic 16:0	2.2 – 52.6
Stearic 18:0	0.37 – 31.4
Arachidic 20:0	0.5 – 7.5
Behenic 22:0	0.4 – 13.03
Lignoceric 24:0	0.06 – 1.21
∑ SFA[1]	11.6 – 71.26
Palmitoleic 16:1	0.87 – 18.97
Oleic 18:1	0.21 – 32.8
Erucic 22:1	0.28 – 2.70
∑ MUFA[2]	27.0 – 39.8
Linoleic 18:2	0.4 – 13.71
Linolenic 18:3	0.27 – 1.74
Cis-11-Eicosatetraenoic acid 20:1	2.27 – 3.84
Arachidonic acid (ARA – 20:4)	0.73 – 42.4
Eicosapentaenoic acid (EPA – 20:5)	0.17 -56.7
Docosahexaenoic acid (DHA – 22:6	0.32 – 8.93
∑ PUFA[3]	5.1 – 43.86
n-6/n-3[4]	0.25 – 2.61

[1]∑ SFA – sum of saturated fatty acids; [2]∑ MUFA – sum of monounsaturated fatty acids; [3]∑ PUFA – sum of polyunsaturated fatty acids; [4]n-6/n-3 – omega 6 to omega 3 ratio.

Table 3: Fatty acid composition (% of total fatty acid) of sea cucumber.

than n-3 PUFA structured in triglyceride form. However, the DHA content of SC gut in our study was low (0.63% of total lipids) compared to other marine organisms such as fish and blue mussels. Other reports have shown EPA content in the range of 0.3-3.9% of total fatty acids, while DHA was not detected in any of the eight dried samples of SC collected from Guangzhou, China. On the contrary, the fatty acid composition of four species of SC from the coast of Malaysia revealed that the EPA and DHA content was very low in all four species, *viz. H. scabra*, *H. leucospilota*, *H. atra*, *S. horrens* compared to other reports.

The content of n-6 PUFA, especially ARA, also varies among different species of SC. The reported ARA levels are in the range of 1.8-14.4% of total fatty acids in different species of dried SC obtained from Guangzhou, China; the wide range of difference in ARA levels of SC species may be due to the water temperature. We have recently reported the levels of ARA at 1.3% of total fatty acids in SC gut from N.L. On the other hand, researchers have reported ARA levels at 20% of total fatty acids for tropical SC species on the Vietnamese sea coast.

SC also contains a significant amount of cerebrosides and sterols. The presence of antiproliferative active 12-methyltetradacanoic acid (antesio 15:0) are found in the lipids of *P. californicus* and *C. frondosa*, respectively. Furthermore, there are several unusual fatty acids, such as two non-methylene interrupted di-unsaturated fatty acids (22:2NMI) and fatty acids containing hydroxyl group (αOH23:1; αOH-24:1) in SC. Variations in fatty acid composition among different species of SC and from different regions are expected due to different environmental conditions, such as diet and natural habitat and climate. These reports suggest that the fatty acid composition of SC varies markedly from region to region. Thus, the beneficial health effects are deemed to vary.

Biological Activities and Health Benefits of SC
SC is an effective remedy of traditional medicine of China, Malaysia, and other Asian countries to treat various diseases. Profound interest has been paid by the researchers of modern medicine to characterize and validate the beneficial health effects of SC. Several scientific reports support the cholesterol-lowering, antibacterial, antioxidant, and anticancer potential of SC collected from different geological regions worldwide; the comparative health benefits of SC from different parts of the world are discussed below.

Effects of SC on Lipid and Glucose Metabolism
Several studies have shown beneficial health effects of SC and its components on lipid metabolism and blood cholesterol levels to target cardiovascular disease, diabetes, and obesity. The hypocholesterolemic effects of SC, *Isotichopus badionotus*, from Coast of Sisal, Yucatan state, Mexico, were reported in a rat model, and the effect was due to alterations in the genes involved in cholesterol and lipid metabolism. Similarly, the polysaccharide-fucosylated chondroitin sulphate obtained from *Acaudina molpadioide* from Qingdao, China, has been shown to improve glucose metabolism in insulin-resistant mice by modulating the metabolic enzymes and promoting the P13-kinase/protein kinase B (PKB)/glycogen synthase kinase 3β (GSK-3β) signalling pathway mediated by insulin. In addition, another polysaccharide called fucoidan from the same SC species was found to induce lower blood glucose levels and improve insulin sensitivity. Further, the saponins obtained from SC, *Pearsonothuria graeffei* (Figure 2), from Qingdao, China, were found to ameliorate obesity, hepatic steatosis, and glucose intolerance in high cholesterol-fed mice by improving the metabolic parameters associated with obesity. We have also reported anti-obesity effects of SC (*Cucumaria frondosa*) gut powder, from N.L., Canada, in both cell culture and animal models. Similarly, EPA enriched phosphatidylcholine from *C. frondosa* from Qingdao, China, exhibited antihyperglycemic effects by activating the PI3 kinase/protein kinase B signalling pathway in streptozotocin induced

Figure 2: Saponins obtained from sea cucumber, *Pearsonothuria graeffei*, help improve obesity, hepatic steatosis, and glucose intolerance in high cholesterol-fed mice.

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hyperglycemic rats. Thus, several studies have established that SC collected from different geological locations displays the potential to lower lipid and glucose levels. From the literature review, the consumption of SC is likely to prevent heart disease and provide beneficial health effects under diabetic and obese conditions. Further studies are needed to confirm whether the difference in the composition of SC has differential health benefits and the mechanism involved.

Antibacterial and Antifungal Activity of SC
SC lives in the abyssal seafloor with several other potential bacterial and fungal pathogens; hence, it could be suggested that it possesses effective bioactive compounds such as antimicrobial agents and peptides to protect against potential pathogens. SC from different geological regions has been shown to possess antibacterial and antifungal activity against human pathogens. Certain species, such as *Holothurian leucopilota* and *Stichopus hermanni*, collected from the Coast of the Persian Gulf and Oman Sea, showed no antibacterial activity. However, these species showed antifungal properties. The bromelain and papain hydrolysates and the active fractions of *Actinopyga lecanora* from Malaysia showed antibacterial activity against both Grams positive and Grams negative bacterial pathogens such as *Pseudomonas Sp.*, *P. aeruginosa*, *Escherichia coli*, and *Staphylococcus aureus*. Similarly, *Parastichopus parvimensis*, from Santa Catalina Island, California, showed effective antibacterial activity against *Bacillus subtilis* and *E. coli*. In another comparative study of the antibacterial activity of organisms from sea sources, the eggs of *C. frondosa* from the coast of Tromso, Norway, were found to possess prominent antibacterial activity against *Vibrio anguillarum*, *E. coli*, *S. aureus*, and *Corynebacterium glutamicum*. *Stichopus joponicus*, collected from Northeastern Jeju Island, Korea, revealed effective antibacterial activity against *S. aureus* and *S. epidermidi*s. The body wall of *H. leucopilota* from the Persian Gulf showed prominent antibacterial activity against oral pathogens such as *Streptococcus salivary* and *S. mutans*. Apart from the antibacterial potentials of SC, the body wall and fluid of the Mediterranean Sea cucumber, *H. polii*, collected from the rocky shore of the bay of Tabarka, Tunisia, was reported to have antifungal activity against filamentous fungi *viz. A. fumigatus*, *Trichophyto rubrum*, and *Candida albicans*. These studies strongly suggest that SC from different parts of the world possess antibacterial and antifungal properties and can be exploited as a natural source to target human pathogens.

In contrast to the above studies, the body wall, gut, cuvierian organs, white string, and coelomic fluid of *H. leucospilota* from the Persian Gulf and Oman Sea showed only micro-static effect against both bacterial and fungal pathogens, *viz*. bacterial pathogens: *Escherichia coli*, *Salmonella typhi*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*; and fungal pathogens such as *Aspergillus niger*; *A. fumigatus*, *A. flavus*, and *A. brasilensis*. Further, *H. scarba* and *S. hermanni* from the Northern Coast of the Persian Gulf did not show antibacterial activity against all tested bacterial pathogens; however, the respiratory tree showed effective antifungal activity against *A. niger*. Thus, there is a need to study the composition and properties of SC from various regions of the world that may be responsible for differential health effects and to understand further the mechanisms responsible for eliciting health benefits.

Antioxidant and Anticancer Properties of SC
Organisms dwelling on the seafloor are often subjected to oxidative stress due to high ultraviolet and other radiation exposure in the seafloor. These organisms are protected from the adverse effect of oxidation, possibly through the presence of endogenous antioxidant compounds; hence, there is the possibility of the presence of novel antioxidant and anticancer molecules. Exploring such novel antioxidant compounds would be essential for the development

of novel drugs. SC from different regions of the world have been explored for their antioxidant and anticancer properties. The fresh and rehydrated samples of *C. frondosa* from the Atlantic Ocean of N.L., Canada, have been shown to possess effective antioxidant activity; the activity was independent of the phenolic compounds. In contrast, the muscles of *C. frondosa* showed antioxidant activity *in vitro*, which was dependent on the presence of phenolics and flavonoids. Others have also shown that the phenolic compounds from SC possess antioxidant and anticarcinogenic properties. For example, phenolic compounds from *H. atra*, Red Sea, Egypt, were reported to possess antioxidant potential. Several other species from Asian countries, such as *H. elduli*, *Stichopus horrens*, *S. badionotus*, *S. variegatus*, and *Bohadschia mamorata* from the Terengganu coastal area of Malaysia and Korea, also possess antioxidant and cytotoxic activity against cancer.

On the other hand, studies have reported that it is the saponins from SC that possess antioxidant and anticancer properties. Saponins derived from *H. lecospilota* collected from the Coast of Qeshm, Bandar Abbas, Iran, were found to have antioxidant and antiproliferative activity against human lung carcinoma cells *in vitro*. Saponins such as Echinoside A from *H. nobilis Selenka*, collected in Dongshan Island, Fujian, China, also showed anticancer activity against prostate carcinoma. Similarly, sulphated saponins derived from *Pentacta quadrangularis* from Guangdong, China, also had antitumour and antiangiogenic activity by inhibiting the proliferation of human umbilical cord vein and human dermal microvascular endothelial cells. The antitumour activity was due to endothelial cell apoptosis, suppression of cell migration, cell adhesion, and tube formation.

Besides saponins, triterpene oligoglycosides isolated from SC from different parts of the world also possess anticancer properties. Triterpenes isolated from *C. okhotensis* in the Sea of Okhotsk, Kamchatka, Russia, showed an antiproliferative effect on human cervical cancer cells. Triterpene glycosides from other species, such as *H. scabra* from the offshore waters of Hainan Island, South China, also possess antiproliferative activity. Thus, triterpenes, phenolic compounds, and saponins appear to be important antioxidant and anticancer compounds found in SC collected from different geological regions worldwide. It will be interesting to explore whether all species have comparable triterpenes, phenolic compounds, and saponins to provide similar health benefits in terms of antioxidant and anticancer properties. Establishing the similarities and differences in various species found around the globe would provide concrete evidence on the health potential of SC.

Conclusion

The proven health benefits of SC have significant commercial potential. The commercial utilization of SC is growing worldwide due to its valuable nutritional constituent and health benefits. However, the nutritional and therapeutic potential of SC from different regions of the world varies dramatically. Thus, it is critical to correctly identify various SC species for commercial grading and establish their health benefits. SC gut is a rich source of n-3 PUFA structured in phospholipids, which could be developed as a valuable PUFA supplement because these are highly biologically active. Furthermore, a comparative study of the health benefits of various species of SC from around the world would help identify the superior varieties with better health effects. Lastly, it is essential to establish the mechanisms by which SC elicits health benefits and to identify the compounds responsible for eliciting those benefits.

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