Global Sea Cucumber Fisheries: Their Culture Potentials, Bioactive Compounds and Sustainable Utilizations

M. Aminur Rahman

***Abstract*—**Sea cucumbers, belonging to the class Holothuroidea, are sessile marine invertebrates, generally found in the benthic areas and deep seas across the world.. They are traditionally consumed raw, dried and boiled in many tropical and subtropical countries. In addition, sea cucumbers have also been popular as a traditional food tonic in China, Korea and Taiwan for thousands of years. Sea cucumbers are believed to exert wound healing and reduce arthritis pain in humans, hence are widely used in Asian folk medicine. In addition, recent scientific evidence supporting their importance as nutraceuticals and functional foods has attracted interest from nutritionists, pharmacologists and the general public. Therapeutic properties and medicinal benefits of sea cucumbers can be linked to the presence of a wide array of bioactives, especially triterpene glycosides (saponins), chondroitin sulfates, glycosaminoglycan, sulfated polysaccharides, sterols, phenolics, cerberosides, lectins, peptides, glycoprotein, glycosphingolipids and essential fatty acids. Sea cucumbers are a valuable resource for coastal communities in the Indo-Pacific region, where they have been exploited unsustainably for decades. In the Asian dried seafood market, the sea cucumbers *Holothuria scabra* (sandfish) and *H. lessoni* (golden sandfish) fetch higher prices than any other tropical sea cucumbers. The premium price for processed sea cucumbers has resulted in increased fishing pressure on wild populations of these vulnerable species. The attractive price for processed sea cucumbers and the declining wild fishery has led to considerable interest among private and government agencies in developing alternative methods of producing beche-de-mer, especially through aquaculture. Sea cucumber aquaculture would provide a permanent solution, making it possible to both enhance declining wild sea cucumber populations through restocking, and provide sufficient beche-de-mer product to satisfy the increasing global market demand in a very significant and worthwhile manner.

***Keywords*—**Sea cucumber, Breeding. Larval rearing, Culture protocols, Bioactive compounds, Benefits Utilizations.

I. INTRODUCTION

AMONGEST the five existing classes of Echinoderms, it is the sea cucumbers (Echinodermata; Holothuroidea) that are both commercially fished and heavily overexploited [1, 2]. SThey are usually occurred in the shallow benthic areas and deep seas across the world [3]. The major product in the sea cucumber is the boiled and dried body-wall, familiarly known as 'bêche-de-mer' or 'gamat', for which there is an increasing demand for food delicacy and folk medicine in the communities of Asia and Middle East [3–7]. Sea cucumber fisheries had rapidly grown and expanded due to the growing bêche-de-mer-related international market, supported by continuing demand of these organisms for aquaculture and biomedical research programs [1, 3]. They have high commercial value coupled with increasing global production and trade and therefore, commercially fished and heavily overexploited in some areas [1, 8]. The widespread and growing interest in this commodity is indicative of strong market-based drivers to increase production of sea cucumber [9]. It also shows that sea cucumbers provide an important contribution to economies and livelihoods of coastal communities, being the most economically important fishery and non-finfish export in many countries [10]. Reconciling the need for conservation with the socio-economic importance of sea cucumber fisheries is shown to be a challenging endeavor, particularly for the countries with limited management capacity. Many sea cucumber fisheries still have no management system or restrictions in place, and for those that do, the scenario for catches to continue even at a reduced level is poor [1]. Cultivation of these species increasingly becomes a necessity, both for stock enhancement programs and as a means to meet up market demand. In addition, as the wild stocks decline, cultivation is more likely to become economically viable.

Dr. M. Aminur Rahman, Laboratory of Marine Biotechnology, Institute of Bioscience, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; E-mail: aminur1963@gmail.com.

II. SEA CUCUMBER BREEDING, REARING AND CULTURE

Usually, the cultivatable species of sea cucumbers are dioecious, broadcast spawners, the fertilized eggs developing into planktonic larvae in the water column before undergoing settlement induction and metamorphosis to the juvenile sea cucumber. The average life span of a sea cucumber is documented to be 5–10 years and the most species attain their sexual maturity at 2–6 years. Cultivation of sea cucumbers initiated in Japan in the 1930s and juveniles of the temperate species *Stichopus japonicus* (Fig. 1A) were first produced in 1950 [11]. During the last 15 years, commercial production in Japan has enhanced, where annually an estimated 2.5 million juveniles are released [7]. In China, cultured rather than fished *S. japonicus* now account for around 50% of the country's estimated annual production of dry sea cucumber [1, 7]. Procedures for mass culture of the tropical *Holothuria scabra* (Fig. 1B) are now well established and practiced in Australia, India, Indonesia, the Maldives and the Solomon Islands [11].

Other tropical species in culture include *Actinopyga mauritiana* (Fig. 1C) and *H. fuscogilva* (Fig. 1 D), with the focus of the research effort centered on the production of juveniles in hatcheries for the restoration and enhancement of wild stocks [7, 12, 13]. However, in the last decade, only a few commercial holothurians have been successfully reared to settlement, including some tropical and temperate species.

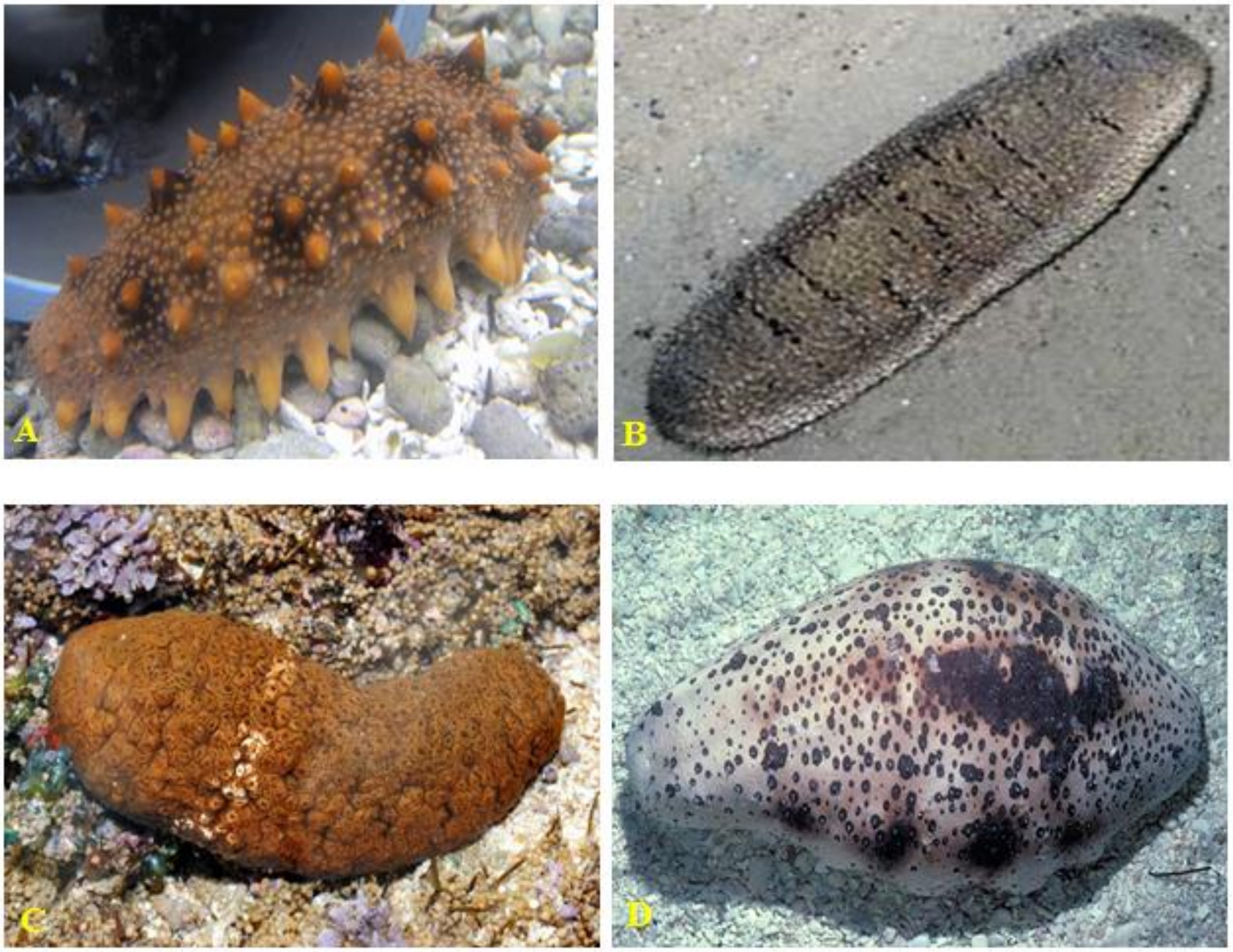

Fig.1. Commercially important species of sea cucumbers in aquaculture: A) *Stichopus japonicas*, B) *Holothuria scabra*, C) *Actinopyga mauritiana* and D) *Holothuria fuscogilva*

Matured brood stock of *Holothuria scabra* is usually collected from the wild and maintained in the hatchery in a bare 1 t polyethylene tank. The water in the broodstock tank is changed daily. Animals are fed with an extract of *Sargassum* sp. and unicellular algae (*Chaetoceros* sp. and *Isochrysis* sp.) [14]. The broodstock is most commonly induced to spawn through thermal stimulation, by increasing the seawater temperature in holding tanks by 3–5°C for 1 h. Generally, *H. scabra* has a bi-annual peak in gonadosomatic index, indicating two spawning periods a year, but closer to the equator, a proportion of the population spawns year-round [1, 11]. After females spawned, eggs are left for one hour to be fertilized. The collected eggs are washed in fresh seawater to remove excess spermatozoa. Eggs are then transferred to three larval rearing tanks that are stocked at a density of 0.7-1.0 eggs/ml. The temperature in the larval tanks is maintained at 26°C. Larvae are usually fed with phytoplankton, including *Isochrysis* sp., *Chaetoceros muelleri*, *C. calcitrans* and *Pavlova lutheri*. The algae are given twice daily, at gradually increasing concentrations of 20,000 cells/ml to 40,000 cells/ml. Complete water changes (100%) are carried out every second day until the late auricularia stage is reached. At the start of the metamorphosis from late auricularia to doliolaria (Fig. 2), preconditioned polyethylene plastic sheeting or rough-surfaced tiles added to the tanks. When settlement plates are placed into the tanks, the pentactula larvae are fed with spirulina powder and Algamac Protein Plus at a concentration of 0.25 g/m^3. Newly metamorphosed juveniles are fed with Spirulina powder and Algamac Protein Plus. When juveniles reached 2 cm, they are fed with *Sargassum* and *Padina* extract. The water in juvenile tanks is changed daily. A fine layer of sand is added to tanks as soon as juveniles reached 4 cm. Throughout the juvenile stage it is necessary to periodically detach the juveniles from the substrate for grading, transfer between tanks or to supply fresh substrates. After a 4-6-month, on-growing nursery phase, and at a length of 2–8 cm, juvenile sea cucumbers are released to managed areas of the seafloor or ponds for advanced rearing and grow-out culture.

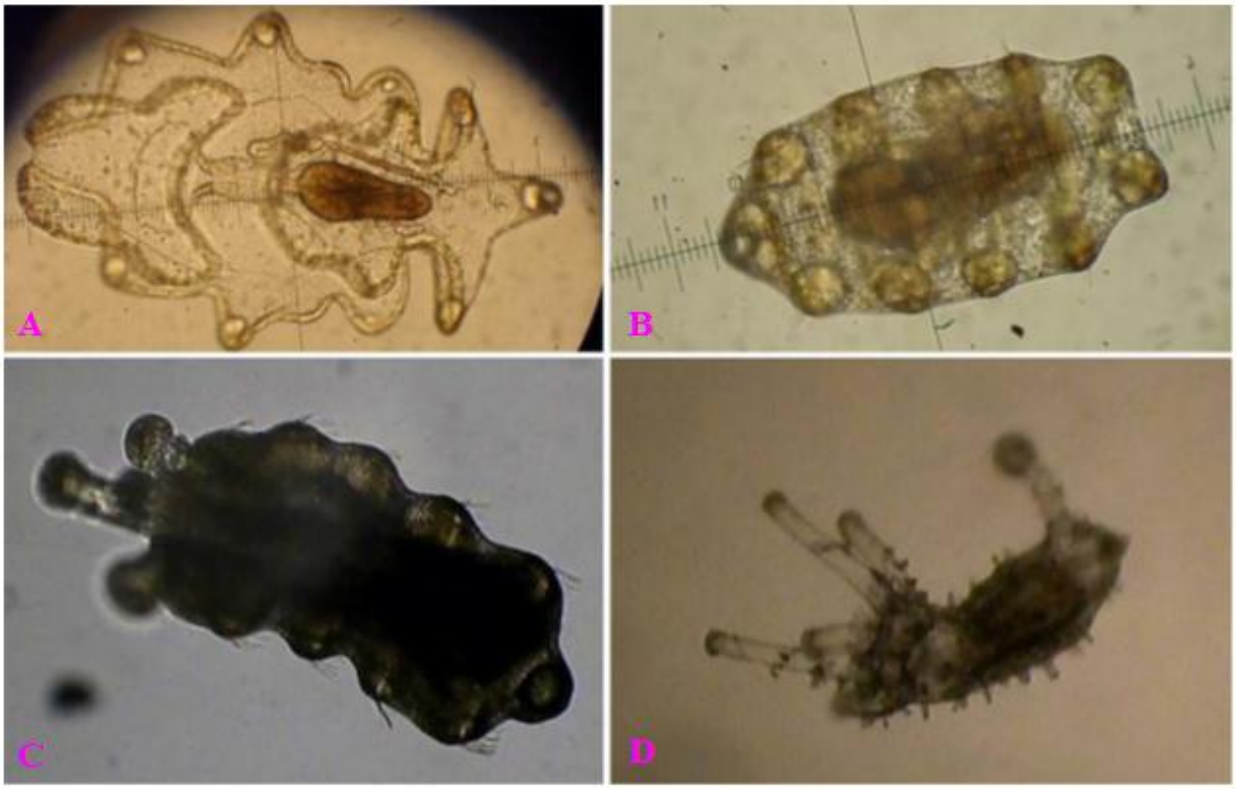

Fig. 2. Larval developmental Stages of *Holothuria Scabra*: A) Auricularia, B) Doliolaria, C) Pentactula And D) Early Juvenile [14]

Aquaculture, sea ranching and restocking has been evaluated as possible solutions to wild sea cucumber overexploitation [7]. Currently, China is successfully producing an estimated 10,000 tons, dry weight, of *S. japonicus* from aquaculture, mainly to supply local demand [7]. Because of the outbreak of prawn diseases in 1990s, lots of prawn ponds were unused and therefore, the farmers started pond culture of sea cucumber in Shan Dong province and Dalian and obtaining higher production with lesser costs and risks (Fig. 3). In the Asia Pacific region, aquaculture is still in the early development stages, with one species of sea cucumber (*H. scabra*) in trials to ascertain the commercial viability of culture and farming options. Many additional threats have been identified for sea cucumber populations worldwide, including global warming, habitat destruction, unsustainable fishing, the development of fisheries with little or no information on the species, and lack of natural recovery after overexploitation. The critical status of sea cucumber fisheries worldwide is compounded by different factors including i) the lack of financial and technical capacity to gather basic scientific information to support management plans, ii) weak surveillance and enforcement capacity, and iii) lack of political will and socio-economic pressure exerted by the communities that rely on this fishery as an important source of income. The pervasive trend of overfishing, and mounting examples of local economic extinctions, urges immediate action for conserving stocks biodiversity and ecosystem functioning and resilience from other stressors than overfishing (e.g. global warming and ocean acidification), and therefore sustaining the ecological, social and economic benefits of these natural resources [10].

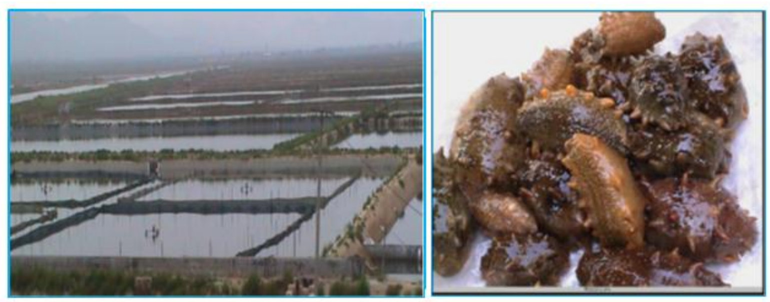

Fig. 3. Current successful aquaculture practices of sea cucumbers (e.g., *Stichopus japonicas*) in earthen ponds in China, obtaining higher production with lesser costs and risks

III. Sea Cucumber Bioactives

Like many other marine organisms, sea cucumbers have been, and continue to be, examined as a source of biologically active compounds with biomedical applications. They have long been well recognized as a tonic and traditional remedy in Chinese and Malaysian literature for their effectiveness against hypertension, asthma, rheumatism, cuts and burns, impotence and constipation [15-19]. Nutritionally, sea cucumbers have an remarkable profile of valuable nutrients such as Vitamin A, Vitamin B1 (thiamine), Vitamin B2 (riboflavin), Vitamin B3 (niacin), and minerals [3]. A number of unique biological and pharmacological activities including anti-angiogenic [20], anticancer [6, 21], anticoagulant [22, 23], anti-hypertension [24], anti-inflammatory [25], antimicrobial [26], antioxidant [27], antithrombotic [28], antitumor [29] and wound healing [30] have been attributed to various species of sea cucumbers. Therapeutic properties and medicinal benefits of sea cucumbers can be linked to the presence of a wide array of bioactive compounds, especially triterpene glycosides (saponins) [31], chondroitin sulfates [32], glycosaminoglycan [33], sulfated polysaccharides [34] sterols (glycosides and sulfates) [35], phenolics [36], cerberosides [37], lectins [38], peptides [39], glycoprotein, glycosphingolipids and essential fatty acids [3]. The present review emphasizes that sea cucumber can be explored as a potential source of high-valued components for functional foods, and the nutraceutical industry. There is a great potential to utilize sea cucumbers to develop not only the valuable functional foods with physiological benefits due to their nutritive value, but also their potential applications towards health benefits and therapeutic uses for human beings. Nevertheless, this important marine resource contains a wide array of functional biologically active compounds that can be isolated and purified to act as ingredients of functional foods and nutraceuticals.

IV. CONCLUSION

In general, aquaculture operations for marine species do not start until the wild stock has been diminished to a point where incomes and lifestyle of the people involved are affected [40].When wild stocks decline, the demand created in the market place raises the price of the product and consequently culturing is more likely to become viable economically. As this review of culture methods has shown, there have been dramatic advances in the culture methods of and sea cucumbers in the last 15–20 years, to the extent that one can conclude that presently the major impediments to successful cultivation are indeed economic rather than biological [1]. For example, it is the cost of producing seed, infrastructure for grow-out systems and artificial diets for growing juveniles to market size rather than the technical difficulty of these operations that will constrain the growth of the industry. At this time, while the reseeding operations that are cost-effective, the 'cost' of the grow-out period being endured by the environment and location. One of the few examples, outside of Japan, of farmed urchins reaching the market place comes from Southern Ireland, where hatchery-reared juveniles are transplanted to rock pools where they can be fed drift algae, until reaching to the marketable size [1, 7]. It could be concluded that the future of the sea cucumber industry is closely linked to that of the fisheries, whose fate will ultimately determine the market forces that will shape this growing industry in a highly significant manner.

REFERENCES

[1] Kelly, M.S. 2005. Echinoderms: their culture and bioactive compounds. In: Matranga, V. (Ed.), Echinodermata: Progress in Molecular and Subcellular Biology. Subseries: Marine Molecular Biotechnology. Springer-Verlag, Berlin Heidelberg, pp. 139–165.

[2] Anderson, S.C., Mills-Flemming, J., Watson, R. and Lotze, H.K. 2011. Serial exploitation of global sea cucumber fisheries. Fish and Fisheries, 12: 317–339.

[3] Bordbar, S., Anwar, F. and Saari, N. 2011. High-value components and bioactives from sea cucumbers for functional foods—A review. Marine Drugs, 9: 1761–1805.

[4] Yaacob, H.B., Kim, K.H., Shahimi, M., Aziz, N.S. and Sahil, S.M. 1997. Malaysian sea cucumber (gamat): A prospect in health food and therapeutic. In: Proceeding of Asian Food Technology Seminar, Kuala Lumpur, Malaysia, p. 6.

[5] Huizeng, F. 2001. Sea cucumber: Ginseng of sea. Zhongguo Marine Medicine, 82: 37–44.

[6] Wijesinghe, W.A.J.P., Jeon, Y. J., Ramasamy, P., Wahid, M.E.A. and Vairappan, C.S. 2013. Anticancer activity and mediation of apoptosis in human HL-60 leukaemia cells by edible sea cucumber (*Holothuria edulis*) extract. Food Chemistry, 139: 326–331.

[7] Rahman, M.A. 2014. Culture potentials of sea cucumbers (Echinodermata: Holothuroidea) and their biomedical applications. In: Kao, J.C.M. and Rahman, M.A. (Eds.), Proc. International Conference on Chemical, Biological and Environmental Sciences (ICCBES'2014), International Academy of Arts, Science and Technology, Kuala Lumpur, Malaysia, pp. 45-49.

[8] Bruckner, A.W., Johnson, K. and Field, J. 2003. Conservation strategies for sea cucumbers: Can a CITES Appendix II listing promote sustainable international trade? SPC Beche-de-mer Information Bulletin, 18: 24–33.

[9] Brown, E., Perez, M., Garces, R., Ragaza, R., Bassig, R. and Zaragoza, E. 2010. Value chain analysis for sea cucumber in the Philippines. WorldFish Center, Penang, Malaysia.

[10] Toral-Granda, V., Lovatelli, A. and Vasconcellos, M. (Eds). 2008. Sea cucumbers. A global review of fisheries and trade. FAO Fisheries and Aquaculture Technical Paper. No. 516, Rome, FAO, 317 p.

[11] Battaglene, S.C., Seymour, J.E. and Ramofafia, C. 1999. Survival and growth of cultured juvenile sea cucumbers. Aquaculture, 178: 293–322

[12] Ramofafia, C., Foyle, T.P. and Bell, J.D. 1996. Growth of juvenile *Actinopyga mauritania* (Holothuroidea) in captivity. Aquaculture, 152: 119–128.

[13] Ramofafia, C., Battaglene, S.C., Bell, J.D. and Byrne, M. 2000. Reproductive biology of the commercial sea cucumber *Holothuria fuscogilva* in the Solomon Islands. Marine Biology, 136: 1045–1056.

[14] Dabbagh, A.R. and Sedaghat, M.R. 2012. Breeding and rearing of the sea cucumber *Holothuria scabra* in Iran. SPC Beche-de-mer Information Bulletin, 32: 49-52.

[15] Weici, T. 1987. Chinese medicinal materials from the sea. Abstracts of Chinese Medicine 1(4): 571–600.

[16] Anderson, E.N. 1988. The Food of China. Yale University Press, New Haven, CT, USA.

[17] Jilin, L. and Peck, G. 1995. Chinese Dietary Therapy. Churchill Livingstone, London, UK.

[18] Chen, J. 2003. Overview of sea cucumber farming and sea ranching practices in China. SPC Beche-de-mer Information Bulletin, 18: 18–23.

[19] Wen, J., Hu, C. and Fan, S. 2010. Chemical composition and nutritional quality of sea cucumbers. Journal of the Science of Food and Agriculture, 90: 2469–2474.

[20] Tian, F., Zhang, X., Tong, Y., Yi, Y., Zhang, S., Li, L., Sun, P., Lin, L., Ding, J. 2005. PE, a new sulfated saponin from sea cucumber, exhibits anti-angiogenic and anti-tumor activities in vitro and in vivo. Cancer Biology & Therapy, 4: 874–882.

[21] Roginsky, A., Singh, B., Ding, X.Z., Collin, P., Woodward, C., Talamonti, M.S., Bell, R.H. and Adrian, T.E. 2004. Frondanol(R)-A5p from the sea cucumber, *Cucumaria frondosa* induces cell cycle arrest and apoptosis in pancreatic cancer cells. Pancreas, 29: 335.

[22] Nagase, H., Enjyoji, K., Minamiguchi, K., Kitazato, K.T., Kitazato, K., Saito, H. and Kato, H. 1995. Depolymerized holothurian glycosaminoglycan with novel anticoagulant actions: Antithrombin III and heparin cofactor II-independent inhibition of factor X activation by factor IXa-factor VIIIa complex and heparin cofactor II-dependent inhibition of thrombin. Blood, 85: 1527–1534.

[23] Chen, S., Xue, C., Yin, L., Tang, Q., Yu, G. and Chai, W. 2011. Comparison of structures and anticoagulant activities of fucosylated chondroitin sulfates from different sea cucumbers. Carbohydrate Polymers, 83: 688–696.

[24] Hamaguchi, P., Geirsdottir, M., Vrac, A., Kristinsson, H.G., Sveinsdottir, H., Fridjonsson, O.H. and Hreggvidsson, G.O. 2010. In vitro antioxidant and antihypertensive properties of Icelandic sea cucumber (*Cucumaria frondosa*). Presented at IFT 10 Annual Meeting & Food Expo, Chicago, IL, USA, 17–20 July 2010; presentation no. 282-04.

[25] Collin, P.D. 2004. Peptides having anti-cancer and anti-inflammatory activity. United State Patent 6,767,890.

[26] Beauregard, K.A., Truong, N.T., Zhang, H., Lin, W. and Beck, G. 2001. The detection and isolation of a novel antimicrobial peptide from the echinoderm, *Cucumaria frondosa*. Advances in Experimental Medicine and Biology, 484: 55–62.

[27] Althunibat, O.Y., Ridzwan, B.H., Taher, M., Jamaludin, M.D., Ikeda, M.A. and Zali, B.I. 2009. In vitro antioxidant and antiproliferative activities of three Malaysian sea cucumber species. European Journal of Scientific Research, 37: 376–387.

[28] Mourao, P.A.S., Guimaraes, B., Mulloy, B., Thomas, S. and Gray, E. 1998. Antithrombotic activity of a fucosylated chondroitin sulphate from echinoderm: sulphated fucose branches on the polysaccharide account for its antithrombotic action. British Journal of Haematology, 101: 647–652.

[29] Zou, Z., Yi, Y., Wu, H., Wu, J., Liaw, C. and Lee, K. 2003. Intercedensides A–C, three new cytotoxic triterpene glycosides from the sea cucumber *Mensamaria intercedens* Lampert. Journal of Natural Products, 66: 1055–1060.

[30] San Miguel-Ruiz, J.E. and García-Arrarás, J.E. 2007. Common cellular events occur during wound healing and organ regeneration in the sea cucumber *Holothuria glaberrima*. BMC Developmental Biology, 7: 1–19.

[31] Kerr, R. and Chen, Z. 1995. In vivo and in vitro biosynthesis of saponins in sea cucumbers (Holothuroidea). Journal of Natural Products, 58: 172–176.

[32] Vieira, R.P., Mulloy, B., and Mourão, P.A. 1991. Structure of a fucose-branched chondroitin sulphate from sea cucumber. Evidence for the presence of 3-O-sulfo-β-D-glucuronosyl residues. Journal of Biological Chemistry, 266: 13530–13536.

[33] Pacheco, R.G., Vicente, C.P., Zancan, P. and Mourão, P.A.S. 2000. Different antithrombotic mechanisms among glycosaminoglycans revealed with a new fucosylated chondroitin sulfate from an echinoderm. Blood Coagulation & Fibrinolysis, 11: 563–573.

[34] Mourao, P.A.S. and Pereira, M.S. 1999. Searching for alternatives to heparin: Sulfated fucans from marine invertebrates. Trends in Cardiovascular Medicine, 9: 225–232.

[35] Goad, L.J., Garneau, F.X., Simard, J.L., ApSimon, J.W. and Girard, M. 1985. Isolation of Δ9(11)-sterols from the sea cucumber. Implications for holothurin biosynthesis. Tetrahedron Letters, 26: 3513–3516.

[36] Mamelona, J., Pelletier, E.M., Lalancette, K.G., Legault, J., Karboune, S. and Kermasha, S. 2007. Quantification of phenolic contents and antioxidant capacity of Atlantic sea cucumber, *Cucumaria frondosa*. Food Chemistry, 104: 1040–1047.

[37] Sugawara, T., Zaima, N., Yamamoto, A., Sakai, S., Noguchi, R. and Hirata, T. 2006. Isolation of sphingoid bases of sea cucumber cerberosides and their cytotoxicity against human colon cancer cells. Bioscience, Biotechnology, and Biochemistry, 70: 2906–2912.

[38] Mojica, E.R.E. and Merca, F.E. 2005. Isolation and partial characterization of a lectin from the internal organs of the sea cucumber (*Holothuria scabra* Jäger). International Journal of Zoological Research, 1: 59–65.

[39] Rafiuddin, A.M., Venkateshwarlu, U. and Jayakumar, R. 2004. Multilayered peptide incorporated collagen tubules for peripheral nerve repair. Biomaterials, 25: 85–94.

[40] Robinson, S.M. 2004. The evolving role of aquaculture in the global production of sea urchins. In: Lawrence, J.M. and Guzman, O. (Eds.), Sea urchins: fisheries and aquaculture. DEStech Publications, Pennsylvania, pp, 343–357.