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Marine carotenoids: bioactive potential and applications

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Abstract

Ocean forms one third of the total earth volume and its huge biodiversity have gained wide attention recently, based on the application in various fields of medicine, nutraceuticals and food industry.Over the years, several works have highlighted the bioactive components from the oceans which are responsible for preventing manychronic illnesses like coronary artery diseases and cancer and carotenoids being one of the main molecules in the list.Carotenoids are a group of isoprenoid molecules generally regarded as pigments and their color ranges from yellow to orange. Marine carotenoids are the pigmented compounds obtained from the vast oceans. Structurally, they are made of isoprene units with long polyene chain with conjugated double bonds. The functionality of each is largely depended on the specific components present in them. Carotenoids of marine origin far competes with the terrestrial forms in acting as an excellent bioactive component and as a functional food.The complexity in structure and also difficulty in assessingthe resources have limited the discovery, identification and isolation of these compounds fromdifferent oceans across the world. However, with the developments in the field of nutrigenomics, advancement in scientific infrastructure, the molecular identification, isolation and mechanism of action of these molecules have revealed its immense potential for the betterment of humankind.

Key words: *carotenoid, sponges, bioactive*

Introduction

Carotenoids are a group of pigments that is responsible for providing the brilliant colour to the organisms. Carotenoidwas first discovered by HWF Wackenroder in the year 1831, from the carrot root *Daucuscarota* and coined the term "carotene" from the Latin word carota. Followed by this, the name "xanthophyll" was coined by Berzelius while experimenting with autumn leaves six years later.(Minguez,2008).Animals cannot synthesize these pigments on their own but are metabolized from the plantsand other photosynthetic organisms by feeding on them. Other than plants, carotenoids are also synthesized by the micro algae, bacteria and fungi also. Biosynthesis of carotenoids in the photosynthetic organisms follow the mevalonic acid pathway.

Carotenoids are responsible to create the fascinating colours of the nature. This property is attributed due to their polyene chain with a number of conjugated double bonds. Due to their high unsaturation and presence of conjugated double bonds they possess enormous health benefits like anticarcinogens, as cardiovascular disease preventors, prevention of age related macular degeneration symptoms etc. Naturally these pigments are found in the form of lycopene, lutein and zeaxanthin in the terrestrial environment. The bioactive properties exhibited by these pigments are attributed to their structural aspects. Recent advances in the pharmaceutical field and food science have listed the compounds of carotenoids to be ideal in treating many chronic diseases.

Marine carotenoids

Globally, the marine species are gaining significance recently due to the characteristic functional properties exhibited by them contrasting the terrestrial beings. This popularity gained over the years is partly due to the possible prevention of several diseases either as direct food consumed or as fortified form in nutraceuticals and drugs. Breakthrough in nutrigenomics and human genome project combined with food formulations using specific bioactive components, have multifaceted the marine species to create new opportunities in the food and pharmaceutical industries. (Miyashita, 2009).

In marine environment carotenoids are responsible for yieldingcolor to the fish, shellfish and various plant species. However, the distribution pattern of these pigments varies in the species based on their habitat and feeding habits. Seaweeds, microalgae, corals, crustaceans all imbibe this colour from the nature either by photosynthesis or depending on organisms that synthesise their food so. Micro algae are the primary source of carotenoids for the aquatic fauna. Diversity of these algal species is more distinct and versatile in marine ecosystem than in fresh water forms. They synthesize carotenoids following distinguished carotenogenesis pathways which can be used as chemotaxonomic markers. (Takaichi, 2011). Many cyanobacteria contain β-carotene, zeaxanthin, echinenone and myxoxanthophyll and the presence of additional carotenoids like nostoxanthin, canthaxanthin and oscillol dipentoside has been noted in a few other species. (Takaichi and Mochimaru,2007). *Tetraselmis suecica* is a marine green microalga rich in tocopherol, carotenoids and chlorophyll exhibiting good antioxidant property and used in human cell lines repair. (Sansone *et al.,* 2017).The notable feature of marine algal carotenoids is their ability to synthesize secondary carotenoid as a by-product when subjected to extreme conditions or exposure to environmental stresses. Under adverse growth conditions these organisms produce the secondary carotenoids which have higher bioactivity properties than the primary products. Prominent species among this category is *Dunaliell asalina* which is known to accumulate 10-13% of dry algal biomass as β-carotene when subjected to extreme environmental conditions. (Lamers *et al.,* 2008).

Macroalgae or seaweeds have long been used as food source by the Asian countries and is being widely cultured in several nations due to its rising demand over the years in various pharmaceutical and nutraceutical industries globally. Palermo *et al.,* (1991) reported the presence of beta carotene, zeaxanthin, fucoxanthin and fucoxanthinol in the red algae. Fucoxanthin is known to be the most abundant carotenoids found in nature, accounting for >10% of the estimated total natural production of carotenoids. (Maeda *et al.,* 2008). Fucoxanthin has significant biological properties based on its unique molecular structure with the presence of an allenic bond and some oxygenic functional groups such as epoxy, hydroxyl, carbonyl and carboxyl moieties making it one of the potent antioxidant in nature. (Nomura *et al.,*1997, Yan *et al.,*1999, Sachindra *et al.,*2007). Seaweeds are also rich source of other carotenoids like β-carotene, lutein, siphonaxanthin. Other marine macroflora possessing these pigmented compounds are the sea grasses. Casazza and Mazella (2002) reported the presence of β-carotene, lutein, zeaxanthin, violaxanthin, neoxanthin and siphonaxanthine pigments from four Mediterranean Sea grass species.

The heterotrophic microorganisms of marine origin like those belonging to the genera Agrobacterium and Paracoccus which are mainly isolated from the coastal ecosystems are known to be rich source of Astaxanthin pigments. (Ambati *et al.,*2014). Further, Shindo *et al.,* 2007 have reported the presence of saproxanthin and myxol two rare carotenoids from new strains of marine bacteria belonging to the family Flavobacteriaceae, possessing higher anti-oxidant activity than the most regularly used β carotene and zeaxanthin. Also, the salt loving haloarchael species produce phytoene, β carotene, lycopene and derivatives of bacterioruberin and salinixanthin. (Rodrigo *et al.,*2015). Recently, *Haloferaxmedi terranei* has been shown to exhibit far better radical scavenging activity than β carotene due to its ability to accumulate high concentrations of bacterioruberin pigments into its cell. (Bumbak *et al.,*2011).

Coral reefs surrounding the world oceans are one of the spell-bound beauties recorded. Different corals, coral reef associated fish, clams (*Tridacna maxima*), mollusks etc are brilliantly colored due to their close association with each other. Corals are filter feeders and are associated with symbiotic zooxanthellae (dinoflagellate algae). These corals are fed upon by the reef fishes and other filter feeding organisms to give them these bright colors. The food chains that link the different organisms through different tropic levels are responsible for yielding this magnificent color to the fishes of marine origin. Similarly, as carotenoids cannot be synthesized by animals *de novo*, it is either directly obtained from food or through some metabolic modifications (Liaaen,1998). The symbiotic microalgae that live in association with the corals contain pigments such as peridinin, pyrrhoxanthin, diadinoxanthin, zeaxanthin, lutein and fucoxanthin during their associations with various cyanobacteria

and algae. (Daigo *et al.,*2008). The marine sponges are brilliantly colored due to the presence of carotenoids like isorenieratae, renieneratane, renierapurpurin etc. these are aryl carotenoids having a cyclic ring and are known to be originated from the marine symbiotic bacteria.(Ramdahl *et al.,*1981)

Crustaceans such as shrimps, prawns, lobster, krill and crab contain astaxanthin as the major pigments which are mainly obtained from the β carotene obtained by feeding on the algae. Similarly the bivalves, star fishes sea urchins also obtain the respective pigments upon feeding on the algae or planktons. Keto carotenoids such as echineone, canthaxanthin, phoenicoxanthin, 4-ketozeaxanthin, fritschiellaxanthin, papilioerythrinone and astaxanthins in free, esterified and protein complexed forms are available in crustaceans. (Matsuno, 2001).Finfishes contain pigments like tunaxanthin in yellow and blue green fish, astaxanthin in red marine fishes, zeaxanthin in anchovies, some flat fishes, sharks and rays, tunaxanthin, luteinsand zeaxanthin in brackish water fishes and lutiens and alloxanthin in fresh water fish. (Matsuno and Hirao, 1989).

Biological functions of carotenoids

Reactive oxygen species and oxidative damage to bio-molecules have been widely postulated to cause and aggravate several chronic diseases including cancer and other cardio vascular diseases. Carotenoids are well known for their health promoting factors as many of the sources are rich in the β carotene pigment which is a very strong antioxidant and also serve as the precursor for Vitamin A synthesis. β carotene is well known for its efficiency in quenching singlet oxygen reducing the risks associated with the oxidative stress in cells. Further, marine carotenoids like astaxanthin and fucoxanthin are more potent in quenching the singlet oxygen species.

The anti-cancer properties of the carotenoids are attributed to its antioxidant activity, gap junction intercellular communication, inhibition of cellular proliferation and enhancement of immunity. (Cooper,2004). Dietary carotenoid intake is known to reduce the risks associated with cardiovascular diseases, age related macular degeneration and cancers.

Table.1: Industrial Application of few promising marine carotenoids

Carotenoids	Promising marine sources	Industrial applications
Astaxanthin	• *Haematococcuspluvialis*	• Animal feed colorant • Nutraceuticals • Pharmaceuticals • Cosmetics (source: www.oilgae.com)
β-carotene	• *Dunaliellasalina*	• Antioxidant agent • Food industry • Cancer and cardio vascular disease prevention • Anti-aging www.grandviewresearch.com)
Canthaxanthin	• *Haloferax alexandrines* • Thraustochytrid strain • *Dietzianatronolimnaea*	• Food and beverage industry • Phramaceuticals • Poultry industry (source: www.gminsights.com)
Lutein	• *Scenedesmussp* • *Chlorella protothecoides*	• Pharmaceutical industry • Pet food • Dietary supplement • Fish feed (source: www.gminsights.com)
Fucoxanthin	• *Laminaria japonica* • *Isochysisaff.Galbana* • *Phaeodactylumtricomutum* • *Odontellaaurita*	• Nutraceuticals • Cosmeceuticals • Pharmaceuticals

Galasso *et al.,* 2017

Inflammation is the response of our body to any tissue damage or infection. But excessive inflammation adversely affects health and results in chronic diseases. The inflammation process is initiated by the synthesis and secretion of pro inflammatory cytokines in the body, intake of foods rich in alloxanthin, diatoxanthin, halocynthiaxanthin has been reported to supress this cytokines (Yoshikawa,2009).

The bioavaialbaility of carotenoids is very significant in imparting the health benefits provided by it. During digestive process, carotenoids need to be solubilized for its uptake by the intestinal epithelial cells. (Maiani *et al.,*2009). Initially the carotenoids undergo dispersion as emulsion (Fig-1) from the food matrix. Digestion of the dietary lipids occurs initially and the carotenoids are solubilized into the bile salt micelles. These carotenoids (which form micelles) are now accessible to the intestinal epithelial cells. Hence bio accessibility is important for the bioavailability of this molecule into the body.

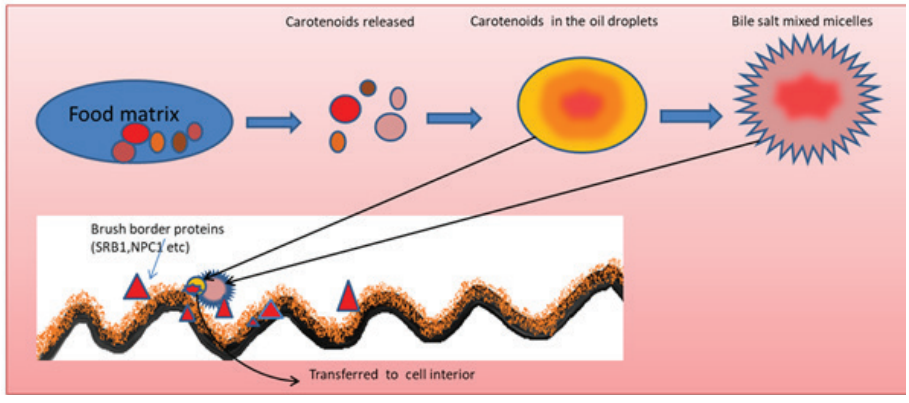

Fig.1: Absorption of carotenoids and mechanisms involved in their health related properties

Applications of carotenoids

These carotenoids are having tremendous applications in Aquaculture as a feed component; they are widely used in cosmetics industry and also in development of aquatic nutraceuticals. Further research and insight into these components are little due to the difficulty to assess these resources. Few industrial applications of the carotenoids are depicted in the table 1.

Conclusion

The excellent bioactive property exhibited by these pigments makes it an ideal health promoting component for the future.Since nature itself is an abundant reserve of these pigments- sustainable and efficient approach can make it the future drug against many chronic diseases.

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