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Review Article

Recent Progress on Carotenoids Production from Microalgae: A review

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ABSTRACT

The color of fruits and green vegetables is attributed to a pigment known as carotenoids. On the basis of presence and absence of oxygen, carotenoids are divided into two categories; carotenes which do not contain oxygen and xanthophylls which are oxygen carrier. Carotenoids are not only good anti-oxidant agents; they also exhibit anti-tumor properties. The structure of carotenoids consists of eight isoprene units, which forms a chain consisting of conjugated double bonds. The presence of conjugated double bond in carotenoids neutralize free radicals by accepting electrons from them. Till now, most of the carotenoids commercially available are produced chemically however, microalgae are a good source of carotenoids. Microalgae can produce the carotenoids in abundance using two-stage cultivation strategies. In first phase, microalgae are given with optimal growth conditions for maximum production of biomass, on the other hand, keeping the second phase for the storage of lipids or carotenoids in unfavorable conditions. The production of carotenoids in two-stage approach is increased by many times than the conventional single phase cultivation method. Carotenoids have many industrial applications.

INTRODUCTION

For thousands of years, several food products with yellow, orange, or red colors attributable to carotenoids have been known and used. Annatto, tomato, Capsicum peppers, maize, and sweet potato are among the most well-known examples that remain untrodden in the Old World but now are native to Americans [1]. After the discovery of New World by Columbus in 1492, they were discovered and was introduced into Europe at the start of 16th century [2]. Plant carotenoids exhibit different stereochemical configurations owing to the presence of conjugated 3-11 double bonds system which is connected to a common C40 backbone. On the basis of presence and absence of oxygen, carotenoids are divided into two categories; carotenes which do not contain oxygen and xanthophylls which are oxygen carrier. However carotenoids can also be classified on the basis of their end group sturcture [3]. Quenching process by triplet state chlorophylls leads to the formation of reactive oxygen species (ROS), also known as singlet oxygen which destroy chlorophyll molecules and many other cellular compartments by carrying out their oxidation. Here comes the essential role of carotenoids in photosynthetic organisms and plants as they protect the photosynthetic framework from photo-oxidation [4]. Carotenoids not only prevent the formation of ROS but also convert preformed ROS into structures that resemble some types of lipids and oxygen-containing epoxides which are unstable in nature [5]. Another important function of carotenoids is their role in formation of plant hormones [6]. Carotenoid are defined as lipophylic isoprenoids which are essentially synthesized by photosynthetic organisms, however, few non-photosynthetic organisms from the domain of fungi and bacteria also possess carotenoids [7]. A large group of lipophylic isoprenoids is synthesized by photosynthetic

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and some non-photosynthetic organisms [8]. The structure of carotenoids consists of eight isoprene units, which forms a chain consisting of conjugated double bonds and an extended system known as p-electron system. This whole structure accounts as a C40, a central backbone, responsible for the absorption of visible light and ultraviolet (UV) radiations [9]. Thus, carotenoids have vital role in light absorbance and energy transfer during photosynthesis and as a protective agent against photooxidative damage. Carotenoids have long been known as an anti-oxidant and coloring agent and there are many supporting evidences about their role in human body and potential health effects [10]. Once carotenoids are assimilated in the body of the organism, they enter biochemical pathways, modify themselves and provide many health benefits like improving sexual behavior and therefore considered essential in many species for reproduction [11]. In the people having low levels of melanin or having light-sensitive skin, carotenoids work together with flavonoids to prevent sun damage caused by UV light [12]. Polyene chains in the structure of carotenoids is chromophoric, giving rise to different colors and performing distinct functions [13]. One of the two major classes of carotenoids is carotenes, which is purely hydocarbon and include compounds like lycopene α-carotene, and β-carotene. The other class is xanthophyll which contain oxygen, the only feature distinguishing it from carotenes, including example like fucoxanthin, zeaxanthin, violaxanthin, lutein, flavoxanthin, and neoxanthin [13]. One of the best sources of natural carotenoids available commercially is microalgae, a subtype of algae. In aquatic ecosystems, microalgae constitute the bottom of food chain [14]. The biomass of microalgae only constitutes about 0.2% of the photosynthetic biomass but it is surprising to know that 50% of the photosynthesis activity occurring globally is carried out by microalgae [15]. Microalgae is also a good source of different metabolites including carbohydrates, proteins, vitamins, lipids, cosmetics, carotenoids, energy production, pharmaceutical industries and for food additives [14].

Health Benefits of Carotenoids

The role of carotenoids is generally established as an anti-oxidant and food colorant [11] with numerous beneficial effects on human health including particular prevention from cardiovascular, cancers, eye and other chronic diseases (Figure 1) [16]. In 1930s, scientists start investigating on the role of carotenoids in human health and established structural relationship between retinol (vitamin A) and βcarotene and also demonstrated their interconversion [17]. For decades, this was the only part of carotenoids and human health that was recognized and discussed, including the role of retinal in vision [10].

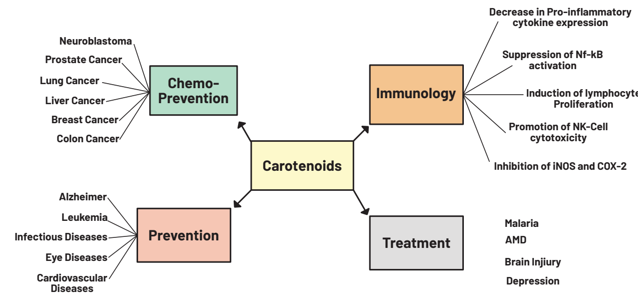

Figure 1: General health benefits of carotenoids

However, in 1970s the role of different carotenoids including non-provitamin A carotenoids as a protective agent in different degenerative diseases was investigated [18]. β-cryptoxanthin, α-carotene, β-carotene, and γ-carotene have pro-vitamin A activity [19]. Role of vitamin A as an antitumor agent was first provided in 1950s in animal models however, later this was attributed to β-carotene, a type of pro-vitamin A [20]. In 1973, the role of vitamin A was studied in rat and mice models in which skin tumors was induced with the results showing that the disease developed slowly in those animals which were fed with red carrots as they are good source of vitamin A [21]. A comparative study on the characterization of carotenoids extracted from red cherry and purple tomato variety was carried out to access their role in the inhibition of tumor cell lines growth by acting as an anti-oxidant. The effect was studied on four different tumor cell lines including HepG2, MCF-7, HeLa, and NCI-H460. The study concluded that both purple tomato and red cherry are good dietary intakes as they have health-promoting potential [22]. The wide spread use of carotenoids as a nutraceutical, feed supplements and cosmeceuticals are seen in aquacultures. Till now, most of the carotenoids in the markets today are produced chemically but consumers, in recent years, are more concerned about safety, environmental burden and public health. This has driven the attention of the producers towards natural carotenoids-based products [21, 23].

Structure and Biochemistry of Carotenoids

β-carotene, zeaxanthin, ASTA, lycopene, and lutein are mostly used for commercial purposes [24]. Many degenerative diseases are caused by reactive species of oxygen and nitrogen generated during aerobic metabolism or pathological changes [25]. The presence of conjugated double bond in the structure of carotenoids neutralize free radicals by accepting electrons from them [26]. Carotenoids is a subgroup of terpenes consisting of eight isoprene units and exhibiting a molecular formula of $C_{40}H_{64}$. Carotenoids like other lipids are soluble in organic

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solvents and their color vary form light yellow to red [27]. They can be categorized in two subgroups named as Xanthophyll or Carotene. The affiliates of the Xanthophyll subgroup have at least one oxygen atom while the affiliates of the carotene subgroup have no oxygen atom at all. Carotenoids are molecules of C30-C50 with a long complex of conjugated double bond that allows them to take up the visible light in the array of violet-green [27]. The kind of visible light taken up is decided by the total of conjugated double bond with the back of carbon. Presence of more conjugated double bonds show that the higher wavelengths are absorbed by pigments [25]. Even though the composition of leaves in higher trees is analogous, the variety of carotenoids in algae is huge and it is very particular in taxa for the most of cases [28]. Carotenoids have two subgroups named as Carotenes that includes a-carotene, b-carotene and lycopene, and the Xanthophylls that includes lutein, zeaxanthin, and violaxanthin [29]. The conjugated system regulates the antioxidant events of carotenoids[30].

Kinetics of Carotenoids

A well-studied aesthetic features is carotenoid colour, which is thought to be condition dependent in a variety of vertebrate species. Pumpkins are high in carotenoid, which is employed in industrial applications such as food, vitamins, pharmaceutical, health care, and cosmetic goods in little or big amount [31]. Carotenoids present in pumpkins are very sensitive and tend to degrade more rapidly so, they need to be conserved appropriately for higher accessibility and good shelf life. There are many preservation methods and drying is also an old method used for preservation of food but the colour of product may change in the drying process because of carotenoid degradation and non-enzymatic reactions. Carotenoids make a big group of more than 650 structures which regulate the red, yellow and orange colour in fruits[32].

Accumulation of Carotenoids in Microalgae

Microalgae comes at lowermost in the food web of aquatic ecosystems. They account for almost half of all photosynthetic activity on the planet and store carotenoids [33]. The most used model for carotenogenesis is *Chlorophyte D. Salina* and this alga is capable of storing the carotenoids more than 14% of their dry weight [34]. Carotenoids which are stored in the microalgae can be categorized in two groups; Primary and secondary carotenoids. Primary carotenoids are vital for existence as they act as structural and functional part of the photosynthetic machinery. Secondary carotenoids when visible to certain environment stimuli start accumulating (Carotenogenesis) [35]. The first commercialized carotenoid was carotene which was extracted from an alga known as *Dunaliella salina* [36]. *Dunaliella salina* is a unicellular, bi-flagellate and bare green alga without any cell wall. Microalgae have the ability to produce a high amount of lipids and carotenoids in unfavourable situations including higher salt stress, higher wavelength, or starvation conditions. On the other hand, stress-based approaches regularly effect the growth of cell in a harmful way and it also reduce the production of preferred products [37].

Two-Stage Cultivation Strategy

To solve the clash of cell growth and important molecules production, two-stage cultivation approach is used giving the very first phase with optimal growth conditions for maximum production of biomass, on the other hand keeping the second procedure for the storage of lipids or carotenoids in unfavourable situations. In one strategy, microalgae were grown-up in the presence of red LEDs with 660nm in the first stage to get the maximum biomass, and in the second stage, stress is induced by green LEDs with 520nm to store lipids. In the same way, a double phase culture approach was applied to raise the production of *Isochrysis galbana* in adequate nutrients and after that cultivating it in the low salt stress conditions for increasing the lipid quantity from 24% to 47% [38].

CONCLUSION

Carotenoids are lipophylic isoprenoids responsible for color development in fruits and vegetable. In the human body, it acts as an anti-oxidant providing major health benefits to human body against chronic diseases. On structural basis, carotenoids are divided into carotenes and xanthophylls. Primary carotenoids have basic involvement in the process of photosynthesis and they are vital for cell survival. Secondary carotenoids are when exposed to certain stress conditions start accumulating (Carotenogenesis). Microalgae can produce the carotenoids in abundance using two-stage cultivation strategies. Carotenoids have many applications in the field of pharmaceuticals, cosmetics and health care.

Conflicts of Interest

The author declare no conflict of interest.

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