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Microalgae for carotenoids production: An update

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Abstract
Pigments have been the subject of a lot of research in the last few decades because of their wide range of applications in medicine, cosmetics, biofuels, the food industry, and many other fields. More than half of all industrial pigments were made with artificial pigments at the time. Because they have been linked to a wide range of cancers and other long-term illnesses in humans, the use of these synthetic pigments has been a major source of worry. To deal with these big problems, natural pigments that come from natural sources might be a good option. When natural pigments were first made, they were made from vegetables. However, as the demand for natural pigments has grown, microalgae have the potential to become a major source of pigment production in the future, as well. Natural food colours have become more popular in recent years because they don't have as much of an impact on the environment as synthetic food colours do. Natural-blend pigments, which have grown in value at a rate of 5% to 10% per year over the last decade, now make up 31% of the world's colourant market, while synthetic pigments make up 40%. So, Algal biotechnology may one day allow for the commercial production of natural pigments on a large scale at a cheap price and in less time because of this.

Keywords: Microalgal species, carotenoids, natural pigments, natural and synthetic carotenoids

1. Introduction

In addition to being a sizeable biological resource, microalgae have the potential to be used to develop game-changing technology and applications. They are small unicellular animals that use photosynthesis to transform sun energy into chemical energy. They are made up of a broad spectrum of bioactive compounds used in a commercial context. Because microalgae use solar energy more efficiently than higher plants, their ability to produce essential compounds or create electricity is well recognized. Microalgae will be used in the future to create a broad variety of metabolites for use in various applications, including health, food and feed additives, cosmetics, and energy generation. Microalgae will also be employed to generate a wide range of metabolites for use in energy production [1-7]. Humans first utilized microalgae 2000 years ago, when the Chinese used Nostoc to survive a famine in their area. Microalgae may be found in a broad range of habitats subjected to harsh climatic conditions. Few carotenoids are specially derived from microalgae; such carotenoids can also be synthesized naturally from plants and synthetically from under lab conditions [8-13].

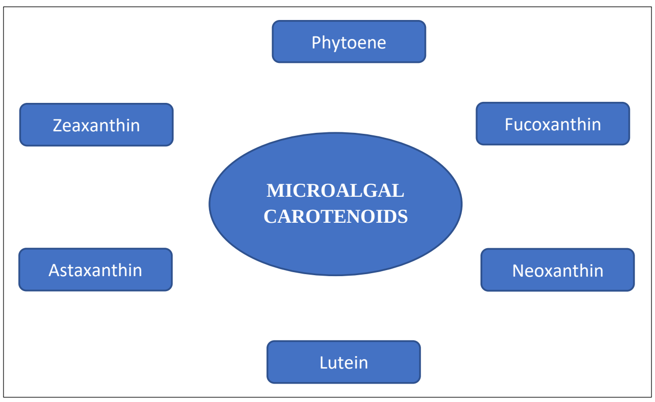

Fig 1: Microalgal carotenoids (Fernandes *et al.* 2018) [18].

Certain carotenoids are produced exclusively through microalgal populations, which are major sources of carotenoid production. These carotenoids are found at deficient concentrations in plants, due to which they are also produced artificially or synthetically in labs. Carotenoids like Lutein, Phytoene, Fucoxanthin (Fig 1.) etc., are produced in microalgal species in adequate quantities, making them very beneficial for the environment and mankind [14-20].

2. The potential of microalgae as a food and nutraceutical source

According to current estimations, microalgae were the first species to appear in the world's oceans roughly 3 billion years ago. Microalgae are a varied category of organisms that include over 100,000 different species. It may be found in the oceans and sources of freshwater (lakes, ponds, and rivers). Microalgae are used for nutrition and nutraceuticals, as well as cosmetic applications. The microalgae constituents widely used as nutraceutical agents are astaxanthin, beta-carotene, polyunsaturated fatty acids (DHA and EPA), minerals, amino acids, single-cell protein, and carbohydrates [21-25]. Many countries, including China, Fiji, and Mongolia, consume microalgal creatures such as Spirulina, Chlorella, and Scenedesmus. In addition to other nutrients, microalgae may supply protein, carbs, and essential amino acids. Microalgae carbohydrates, such as glucose and other polysaccharides, are more digestible than macroalgae carbohydrates [26-30]. The docosahexaenoic acid (DHA) contained in microalgae is thought to be essential for the development and functioning of the brain and other tissues like the cortex, retina, and reproductive organs. DHA has previously been used to treat inflammatory diseases, tumours, and cardiovascular issues [31-36]. Microalgae have a high quantity of proteins, and the amino acids contained in them are similar to those found in other foods. Microalgae contain various carbohydrates, including starch, glucose, sugars, and different other polysaccharides [37-42]. The most frequent carotenoids found in microalgae are astaxanthin, beta-carotene, lutein, zeaxanthin, lycopene, and bixin. Microalgae products for human nutrition are also available in a variety of formats, including pills, capsules, and liquids, among others. They're also in meals like pasta, snacks, gum, and candy bars, as well as drinks. Microalgae extracts are often used on the skin and in cosmetic goods (i.e., Anti-aging cream, emollients, and anti-irritant in peelers). Cosmetics for skin and hair care, such as ultraviolet (UV) protection, are also made from microalgae. Table 1 compares the general composition of several microalgae populations to the composition of different food sources [43-50].

Table 1: Basic compositions of various microalgae species (% of dry matter) (Demain *et al.* 2018) [12].

Microalgae species	Carbohydrate (%)	Protein (%)	Lipid (%)
Anabaena cylindrical	25-30	43-56	4-7
Chlorella vulgaris	12-17	51-58	14-22
Dunaliella salina	32	57	6
Scenedesmus obliquus	10-17	50-56	12-14
Synechococcus spp	15	63	11
Chlamydomonas Rheinhardii	17	48	21

3. Bioactive compounds from microalgae

Microalgae have a vast and unknown pool of unique chemicals, many of which are thought to have a biological function and hence provide a possible source of novel medications. Microalgae have the potential to be a valuable natural source of novel biologically active chemicals that might be used as functional components in a wide range of goods [51, 52]. Table 2 contains a list of bioactive compounds and the algae from which they were obtained.

Table 2: Few bioactive compounds with their different algal sources (Saini *et al.* 2017) [91].

Microalgae	Bioactive compound	Reference
Scenedesmus spp	Lutein, β Carotene	Del Campo *et al.* 2007
Dunaliella salina	Carotene, β Carotene, Zeaxanthin	Grewe *et al.* 2008; Lamer *et al.* 2012
Chlorella spp	Astaxanthin, β -Cryptoxanthin, Canthaxanthin, vitamin C	Inbaraj *et al.* 2006; WuZ *et al.* 2007
Haematococcus Pluvialis	Astaxanthin, Canthaxanthin, Lutein	Jaime *et al.* 2010
Euglena gracilis	Biotin, α -Tocopherol, β -Carotene, Astaxanthin, Anthaxanthin, Neoxanthin	Afiukwa *et al.* 2007; Sahidi *et al.* 1998; Catharina *et al.* 1998; Li *et al.* 2008

4. Microalgal biotechnology

Commercial uses for microalgal biotechnology are being investigated. Microalgae, being photosynthetic organisms, contains chlorophyll, which may be used to make food and cosmetics [53-56]. Additionally, since some microalgae species produce bioactive compounds like antioxidants, antibiotics, and toxins, they may be used in the pharmaceutical industry [57-60]. Additionally, microalgae are used as nutritional supplements for humans due to their high protein, vitamin, and polysaccharide content. Certain microalgae species have high e lipid concentrations to collect and convert into biofuels [61-63]. Microalgae are capable of reducing emerging environmental concerns. For instance, greenhouse impacts and industrial water contamination are essential concerns. Microalgae, via photosynthesis, may contribute to reducing carbon dioxide emissions from power plants while simultaneously providing nutrients efficiently and at a low cost. Additionally, microalgae can fix nitrogen while absorbing heavy metals and phosphorus, which benefits the ecosystem [64-70].

Microalgal biotechnology has placed a premium on creating nutritional supplements generated from microalgae throughout the past several decades. Chlorella (Ram *et al.*, 2020) [77], Dunaliella [71] and Spirulina [72] dried biomass or cell extracts have dominated the economic potential in recent years [73]. They are primarily aimed at the nutraceutical or health food industries and total hundreds of millions of dollars. The interest in unicellular algae as a source of oils and fatty acids to manufacture these compounds has risen significantly in recent years. The Solar Energy Study Institute undertook a substantial chunk of the research with the initial goal of harnessing algae oils as biofuels [74].

5. Carotenoids

As known, the carotenoids and chlorophyll pigments play a major important role in photosynthesis and assist the plants in many ways. Not only this, carotenoids are known to protect the plant cells when the plant is exposed to high temperatures or maximum sunlight. These carotenoids are a significant class of pigments similar to chlorophylls, anthocyanins etc., in promoting color to the plants, fruits and flowers [75-26]. These pigments help in the development of the plants indirectly by increasing the content of vitamins and essential molecules necessary for the plants' growth. These carotenoids are very beneficial not only to plants but also to humans in a way in which these carotenoids are converted into Vitamin A in humans, thereby maintaining eye health. Also, these carotenoids are directly or indirectly related in maintaining the growth of the cells and increasing immune response in humans by increasing the immunity towards certain diseases [77].

There are over 1000 carotenoids in general and are characterized into two categories which are Xanthophylls and B carotene depending on their roles and color imparted. These carotenoids are found in almost all higher plants and algal populations. Especially in case of algae these carotenoids are highly known for their beneficial roles by providing nourishment to the growing algae, conversion of carbon dioxide into solid forms through carbon sequestration, acting as accessory pigments for photosynthesis by transferring light energy received by them and many other roles [78].

These carotenoids can be synthesized synthetically even though they can be obtained naturally. Synthetic production of carotenoids is carried out in many ways using different chemicals and making them readily available for humans as nutritional supplements. Especially in medical biotechnology and agricultural biotechnology, this artificial or synthetic production of carotenoids is gaining much importance in recent years due to the several advantages of carotenoids to humans [79-81].

The carotenoids derived from plants are naturally occurring. Still, due to the increasing demand, these naturally occurring carotenoids like lycopene, lutein etc. (Table 3) are synthesized from natural resources like microalgal species. Whereas certain carotenoids even though they are available naturally are derived artificially due to their less abundance such type of carotenoids include B- carotene, astaxanthin and canthaxanthin [82]. These are highly nutritious and beneficial to humans in many ways to meet the health requirements in humans. Also, these carotenoids are synthesized artificially in yeasts or bacteria under controller laboratory conditions [83-88].

The mass production of these carotenoids is possible through the microalgal populations through which natural carotenoids could be obtained [89, 90]. These carotenoids obtained naturally through microalgae are highly beneficial not only to humans and industries but also to the algal bodies in a way that these carotenoids are helpful in light harvesting and removing excessive reactive oxygen species. Therefore, carotenoids being the most crucial compound to humans, plants, and microalgal populations gained much importance due to their irreplaceable roles in plants and humans and many food industries as natural coloring agents [91].

6. Growth and Carotenogenesis parameters in a carotenoids-producing microalgal culture

Compared to terrestrial crops, microalgae may produce ten to twenty times the biomass per unit area as terrestrial crops. Microalgae can be grown in a variety of habitats, including ocean water, lakes, fisheries ponds, and paddy fields, and they are extremely efficient at utilizing waste nutrients. Traditional plants offer a number of benefits over microalgal cultures, which also have a number of advantages [94-97].

The following are a few benefits of microalgal cultivation that one should be aware (Gong *et al.*, 2020) [21].

- Increased output per hectare of land, leading in decreased land use
- Water use per unit of biomass is limited.
- The plant's high protein, lipid, carotene, and vitamin content per unit area
- Carbon sequestration is a term that refers to the process of storing carbon.

Microalgae can capture CO_2 and solar energy and convert them to biomass through the photosynthesis process. The ambient CO_2 concentration (about 350 parts per million) is insufficient for further growth, and CO_2 collection is complicated by mass transfer from the atmosphere to the culture medium [98]. CO_2 is a greenhouse gas produced by fuels, which may be collected at a cheap or no cost from fossil fuel power plants. Additionally, it may be utilized to promote the growth of algae. Algae cultivation is often achieved in one of two ways. Pond systems are classified into two types: open and closed. The most prevalent pond system is an open pond [99].

6.1 A network of open ponds

Microalgae may be cultivated in a variety of open pond systems, including lakes, lagoons, ponds, artificial ponds, and containers. Open ponds are often easier to construct and operate than closed systems, which is one of their primary benefits. On the other hand, open ponds have several disadvantages, including poor light use, evaporative losses, and CO_2 penetration into the environment [100]. All contaminants in an open pond system influence microalgal development.

6.2 A closed pond system

Microalgae may be grown in closed systems such as ponds and photo bioreactors (PBR). One of the most major advantages of a closed pond system is the ability to change and maintain stable and constant parameters such as carbon dioxide percentage, fertilizers, and light. It does not require large area of land. They do, however, have a number of disadvantages, including their complexity in terms of design, operation, and maintenance [101]. Algae cultivation is similar to agriculture in that it requires both major and minor nutrients to thrive. Carbon, nitrogen, phosphorus, and potassium are the four major nutrients necessary for algae production. Additionally, sufficient sunshine, a good temperature, and sufficient activity are required for it to be successful. Certain algae that are not edible to humans may grow in waste water, including industrial waste, municipal waste, and contaminated water. Typically, companies emit smoke during boiler service, which pollutes the air and significantly raises the ambient temperature [102-109]. Algae convert carbon dioxide to oxygen and polluted water to irrigation water during the photosynthetic phase of their life cycle. Numerous authors have identified the cultural parameters necessary for the indoor development of numerous algal species, as well as the production of carotenoid from algae, in peer-reviewed publications [110-113].

7. Microalgae development factors

When cultivating algae in open ponds or closed photo bioreactors, a diverse variety of environmental factors must be maintained in order for the algae to flourish. Temperature, light, pH, and nutrients all affect not just algae's photosynthesis and growth rate, but also the activity of their cellular metabolism and the makeup of their cellular membranes [114].

7.1 The nutrient effect
Algae growth and development are influenced by a range of factors, including sunlight, temperature, and the availability or lack of nutrients in the surrounding water. Apart from the carbon source, the most critical inorganic elements required for algae development are nitrogen, potassium, phosphorus, magnesium, calcium, Sulphur, and iron. Certain elements, also referred to as micronutrients, are necessary in trace amounts for the body to operate effectively [115].

7.2 The illusory effect of light
A critical external component is the amount of incoming light energy available for algal development. Algae are autotrophic creatures, which means they need a significant quantity of incoming solar energy or insulation to survive. When the photon flux density at the culture's surface is compared to the illuminated surface area, the amount of light energy produced by a photosynthetic culture during a certain time period may be calculated. The availability and intensity of light are critical elements in affecting photosynthetic cultivation's productivity. Increased light intensity encourages algae to consume nitrogen and produce carotenoid pigments [116].

7.3 The effect of pH
pH controls the degree to which chemical compounds and biological metabolites are ionized and hence has a significant effect on their absorption and reactivity. The speciation differential availability of inorganic carbon species (CO_2/HCO_3-/CO_{3-2}) in the growth medium is a critical pH-dependent process in microalgae production. Phosphate co-precipitates with calcium, magnesium, and carbonate in the presence of high carbonate concentrations also trace metals are insoluble and unavailable at high pH; intracellular pH control; and increases in nitrate and phosphate absorption are all seen [117].

7.4 The temperature effect
The effect of temperature is known to be more in case of microalgal growth because temperature effects the growth and multiplication of the microbial strains. Keeping this in mind the strains selected for experimental purpose should be selected carefully as the temperature has maximum effect on the strains [118]. Therefore, controlled temperature conditions are always advisable in experimental conditions. These microbial strains are greatly affected in a way in which the temperature conditions under 15 ℃ and above 40 ℃ is known to be fatal as these conditions promote the degradation in the growth of these algal strains. The growth of these strains majorly affected by the temperature conditions which are to be maintained under optimum conditions which is a problem under natural areas or environments which ultimately results in the loss of nutrient rich microbial strains which in turn reduces the biomass and lipid content of these algal species [73, 74].

7.5 The salinity effect
Different strains of microbes respond differently to salinity conditions. But most of the strains of microbes are less tolerant to salinity and exhibit the loss of biomass and lipid production which is the major and important aspect of microbial strains [99-103]. The microbial algal strains present in marine water and fresh water respond differently under saline conditions. Especially in case of marine algal species salinity is not a major problem as these species are highly tolerant to high saline conditions due to presence of abundant salts in seas and oceans, but in case of fresh water algal strains which are constricted to controlled environmental conditions are highly sensitive to saline conditions. If these fresh water algal strains if exposed to saline conditions up to an optimum level does not cause much effect but if these fresh water microbial strains if exposed to high saline conditions as marine environment these algal species show reduced growth and ultimately die. However, certain algal species are known to be saline tolerant to a certain extent of 0.2-0.4M and are able to produce biomass and lipids [104].

7.6 Carbon dioxide effect
As known carbon dioxide is a very dangerous and high problematic gas causing damage not only to the environment but also causes health issues in humans and animals. This carbon dioxide content rises due to the rise in deforestation causing many small microbes and organisms to die. In case of microbial algal strains this carbon dioxide gas is utilized and converted to form solid substance so that the pollution in the atmosphere can be greatly reduced [56]. The process of sequestration involves in converting the atmospheric carbon dioxide gas into solid substances which gets deposited in the soils o that the harmful effects caused by these gases can be minimized up to a greater level. This reduced carbon gas is utilized later under required conditions. The higher the carbon level in the atmosphere the greater the carbon sequestration occurs and the greater reduction in the environmental damage caused by this gas [44]. Certain species like *C. gracilis* are known for carbon sequestration up to a greater level even under high carbon dioxide content in the environment. Therefore, the microbial algal strains under high carbon dioxide conditions are known to reduce the damage caused by these harmful gases through carbon sequestration method which is a major advantage to the plant as well as environment [117].

8. Production of carotenoids and their extraction procedure
There are several ways in production and extraction carotenoids from plants, microalgal bodies and synthetic means. Previously the production of these carotenoids is only through plants but recently new technologies in biotechnology along with improved methods were derived to produce carotenoids in a huge amount. This production of carotenoids is gaining much importance in recent years due to their several roles in medicine, cosmetic fields, nutritional supplements, natural colorants and several biotechnological purposes. Synthetic or artificial means of carotenoids production is carried out through yeast and microbes. New strains of yeasts and bacteria are used now a days for the production of carotenoids. The process of extraction of carotenoids from plant tissues and microalgal bodies is almost similar but the concentration of carotenoids differs. There are several fungal and bacterial groups that assist in the production and extraction of different carotenoids that are highly useful for industries and mankind. These microorganisms play a major role in producing very useful carotenoids that are highly needed as nutrient feed for humans [50].

Table 3: Microbes used in carotenoid production [59].

Microorganism	Type of microorganism	Carotenoid produced
Escherichia coli	Bacterial strain	Lycopene
Escherichia coli	Bacterial strain	B-carotene
Escherichia coli	Bacterial strain	Zeaxanthin
Flavobacterium	Bacterial strain	Zeaxanthin
Corynebacterium glutamicum	Bacterial strain	Astaxanthin
Blakeslea trispora	Fungal strain	β-Carotene and lycopene
Rhodosporidium sp	Fungal strain	Torulene, β-carotene
Sporobolomyces roseus	Fungal strain	Torularhodin, β-carotene, torulene
Saccharomyces cerevisiae	Fungal strain	β-Carotene
Rhodosporidium toruloides	Fungal strain	β-Carotene

There are several microbial species that assist in the production of carotenoids that are highly useful for industries as well as humans. Such microbes are collectively taken and properly maintained and are allowed to grow under controlled conditions so that they can produce the needed carotenoids in a maximum concentration. Out of many bacterial strains available E. coli is known to produce important carotenoids (Table 3) also many yeasts are also responsible for the growth and extraction of important carotenoids like B- carotene, lycopene etc. (Table 3). These microbes are sent for mass production so that along with the multiplication for microbes the carotenoid production is also enhanced.

9. Production and extraction of carotenoids from microalgae and plants

Compared to artificial or synthetic systems that produce carotenoids natural sources like plants and microalgae are high beneficial due to high production of these carotenoids with cent percent quality. Many plants are known to provide carotenoids that are the important compounds of that particular plant. These plants have added advantages with the presence such carotenoids where these carotenoids enhance the nutritional status of the plants also helping the growth and development of the plants.

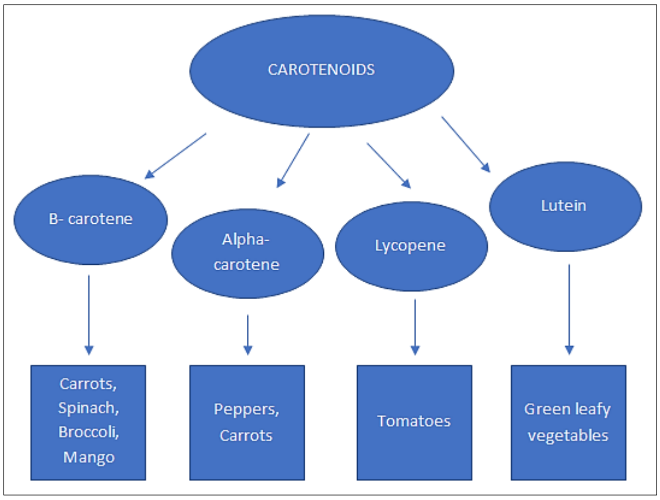

Fig 2: Different sources of carotenoids in plants (Luo *et al.* 2020) [63].

Several vegetables and fruits are responsible for producing different carotenoids that are highly useful and are essential compounds of that particular fruit or vegetable. For example, Lycopene in tomatoes is very essential carotenoid which enhances the taste and nutritional quality of tomatoes and imparts red color to the fruits as well (Fig 1.). Also, several other fruits and vegetables are known to contain similar carotenoids which is highly essential, beneficial for the growth and have several advantages for increasing immunity in humans. Carrots, broccoli, spinach and mango were known to contain B-carotene (Fig 1.), which is the major carotenoid present in these fruits and vegetables. In plants the amount of carotenoids present is of less quantity and the production is also restricted due to many reasons like environmental influences, less plant population, improper growth conditions, nutritional status etc. due to this the carotenoid production is low in plants compared to that of microalgae. In case of microalgae the production of carotenoids is very high due to fast multiplication of the algal species also the environmental issues are not a big deal until unless the conditions are very severe. These species are adaptable to any environmental conditions and are able to cope up with stresses up to a greater level. Also, the concentrations of carotenoids present in algal species is very much high compared to normal plants due to which these microalgal species are highly used and recommended in carotenoid production under controlled lab environment so that the output i.e., carotenoids are greatly used in different areas of study like medicine, beauty and nutraceuticals (Song *et al.*, 2020) [108].

10. Important microalgal species for carotenoid production

Similar to plants several algal species are known to contain carotenoids with maximum production and in different forms. These algal populations are easy to grow and can adapt to any environmental conditions. Also, these species can grow faster and adapt to any situations up to an optimum level. The major advantage of these microalgal species is that photosynthesis is carried out accurately and the moisture availability is maximum so that the growth of these species is more and applies the same to the carotenoid production. Compared to many other microalgal species available in nature few of these species are known to produce many useful carotenoids that are highly beneficial for humans. Certain keto carotenoids like Astaxanthin and Canthaxanthin are gaining much importance in recent years due to their wide applications in human nutraceuticals and animal feeding due to their beneficial health promoting properties. Both the keto carotenoids like Astaxanthin and Canthaxanthin are produced by the same microalgae i.e., Haematococcus pluvialis where such microalgae are known to be highly beneficial due to their production of multiple carotenoids [92]. The purest form of carotenoids extract was obtained after a series of steps from which the plant extract is prepared through maceration of the tissue. Beginning with the selection of the plant, cleaning and proper tissue digestion, followed by saponification to the removal of impurities and solvent extraction. Immediately the organic compounds like xanthophylls, sterols etc., present in the crude extract were removed and the solvent is evaporated by keeping it uncovered or heating the beaker after which the crude form of carotenoids were obtained which are immediately recrystallized through which further more minute impurities were removed. The final form of carotenoids which are obtained after all the screening steps is the purest form of carotenoids without mixing up of other organic compounds. This pure carotenoid can be analyzed using spectrophotometry or chromatographic techniques like thin layer or liquid chromatographic techniques and measured in mg L-1.

Through this procedure of carotenoids identification and extraction several carotenoids are extracted in less time and in large quantities. There are few companies all over the world that promote the growth of microalgal bodies and increasing the carotenoid production which will be a powerful nutritional supplement for humans. As known carotenoids pose several benefits to the growing plants as well as humans due tot heir unique nature of increasing immunity in humas the production these carotenoids under the wing of biotechnology was given much importance. There are several countries that are encouraging the production carotenoids through microalgal populations. Due tot the importance of carotenoids in day to day lives several companies started the production using microalgal sources. These carotenoids are well known in enhancing immunity in humans, reduces the risk of cancers and heart attacks also increasing the eye health and several other benefits [96, 97].

Therefore, compared to carotenoid production from plants and some other artificial means the microalgal bodies are known to provide the best outcome in carotenoid production. Even though synthetic carotenoids are produced in large quantities certain side effect like cancers and indigestion, if taken high doses they are known to cause death. To reduce these effects caused by over intake of carotenoids consulting a doctor or following doctors' prescription is very much advisable. Also, synthetic carotenoids unlike natural carotenoids contain traces of certain chemicals which can be lethal to the consumer. In present day biotechnology production of carotenoids through natural means is gaining much importance to increase the nutritional values of humans. Especially microalgal strains are highly recommended for the production of carotenoids. Thus, microalgal population is a boon in the field of biotechnology for carotenoid production.

11. Conclusion and future prospects

In present day Biotechnology is gaining much importance and it is an emerging field of study which paves way in the production of vaccines, targeted drugs, genome sequences, gene editing techniques, production of organic compounds like carotenoids and many others. Carotenoids are gaining much importance from past 10-15 years due to their important properties in improving the health status of humans and also many other beneficial effects on the plant itself. These carotenoids are known to protect the plant from high sunlight thereby acting protecting pigments along with absorbing the sunlight and promoting photosynthesis thereby acting as accessory pigments along with chlorophyll. Apart from these important qualities of carotenoids they are highly known to reduce the carbon dioxide content in the surrounding environment through carbon sequestration technique which is a highly advantageous property of carotenoids in protecting the plants from the harmful gasses. Also, in humans' carotenoids are known to play major roles like increasing immunity, maintains eye health and reduces the risks of cancers and heart strokes. Therefore, the optimum intake of carotenoids in the prescribed form is very much advisable to maintain natural immunity in the body than depending upon synthetic medicines.

Plants are the major sources of carotenoids production, the flowers, fruits are known to contain maximum carotenoids which helps the plant to maintain its own health and also aids in color development of fruits and leaves. But now a days microalgal cultures or algal populations are gaining much importance in carotenoids production. These microalgal bodies are easy to multiply, quick in growth and importantly they can adapt to any environmental conditions. These microalgal species can withstand unfavorable temperature conditions to a maximum extent. Also, these species have an ability of increased root length to draw water from the deeper level under drought conditions. Therefore, much carotenoids are produced similar to plants through microalgal bodies under natural or artificial environments. The regions for microalgal production used for carotenoid synthesis are to be maintained well with controlled conditions in order to obtain maximum output.

Therefore, it was well understood that microalgal pieces play a unique and yet very important roles in carotenoid production compared to plants and synthetic means. The microalgal populations are natural way, cheapest and a very quick way of carotenoid production. Maintenance of algal populations, carotenoid productions and extraction of carotenoids is quiet an easy way through microalgal species. Also, maintenance of the final output that is pure form of carotenoids can be well maintained and can be stored in form of powder for several days. Also, the manufacture of capsules, tablets and powdered form of carotenoids can be used in nutraceuticals.

12. Future prospects

- To focus on increasing the diversity of microalgal populations for carotenoids production.
- To increase other benefits from microalgal species other than carotenoids.
- To expand the understanding and focus towards green chemistry.
- Improving cultivation of microalgal populations and downstream extraction of carotenoids in less time.
- Increasing the production of carotenoids through natural sources like microalgae by extending markets.
- To focus on algal species improvement for high yields.
- Enhancing the growth rate and reducing the climate limitations for the growth of algal species.
- To reduce the losses caused by biomass contaminations.
- To reduce the production costs and increasing the availability of carotenoids is also important.

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