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Review Article

The Final Development Related Microbial Pigments and the Application in Food Industry

Filiz YANGILAR[1*], Pınar Oğuzhan YILDIZ[2]

[1]Department of Nutrition and Dietetics, Faculty of Health Sciences, Erzincan University, 24000, Erzincan, Turkey
[2]Department of Food Engineering, Faculty of Engineering, Ardahan University, 75000, Ardahan, Turkey

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ABSTRACT

The successful marketing of natural pigments derived from microorganisms and microalgae or extracted from flowering plants, both as food colorants and nutritional supplements, reflects the presence, and importance of markets in which consumers are willing to pay a premium for “natural healthy ingredients”. As known, pigments prefer in natural products have antioxidant, antimicrobial and antimutagenic activities. The most commonly used food grade pigments are chemical compounds containing nitrite and nitrate salts and these synthetic compounds have carcinogenic and teratogenic effects. As colorant substances, natural pigments are very important. Natural pigments sourced from ores, insects, plants and animals were the colorants used since prehistoric period. The industry is now able to produce some microbial pigments for applications in food, pharmaceuticals, cosmetics and textiles. Microorganisms and microalgae as sources of pigments for food use: an industrial reality. The utilization of agro-industrial residues for pigment production may represent an added value to the industry and an environmental-friendly way for waste management. It is emphasized in the present review that is microbial pigments therapeutic potential and assess the potential roles of in food industry.

Keywords: microbial pigments; food industry, biological properties

Mikrobiyal Pigmentler ile İlgili Son Gelişmeler ve Gıda Endüstrisindeki Uygulama Alanları

ÖZET

Mikroorganizmalardan/alglerden veya bitki özütlerinden elde edilen doğal renk maddeleri hem gıda renk bileşenleri hem de gıda katkı maddeleri olarak tüketici isteklerini karşılayan “doğal sağlıklı katkı maddesi” olarak başarılı market uygulamaları yansıtmaktadır. Bilindiği gibi, antioksidant, antimikrobiyal ve antimutajenik aktiviteye sahip olan renk maddeleri doğal ürünler olarak tercih edilmektedir. Karsinojenik ve teratojenik özelliğe sahip sentetik bileşiklerden nitrit ve nitrat tuzlarını içeren kimyasal bileşikler en fazla kullanılan sentetik gıda renk maddeleridir. Renk maddeleri olarak doğal pigmentler çok önemlidir. Doğal renk madde kaynakları tarih öncesi zamandan beri kullanılan bitki, hayvan ve böceklerden elde edilen renklendiricilerdir. Günümüzde endüstriyel olarak gıdalarda, farmakolojide, kozmetik ve tekstilde kullanılmak üzere bazı mikrobiyal renk maddeleri üretilebilmektedir. Mikroorganizmalar ve alglerden endüstriyel olarak elde edilen renk maddeleri gıda üretiminde kullanılan renk maddeleri kaynağıdır. Renk üretimi için tarım-ziraat atıklarının uygulanabilirliği sanayi ve atık yönetiminde çevre dostu bir yöntem olarak ilave bir etki sunabilir.

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*Correspondence to: fyangilar@erzincan.edu.tr
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Sunulan derlemede mikrobiyal pigmentlerin terapotik etkileri ve gıda endüstrisindeki potansiyel rolleri vurgulanmıştır.

Anahtar kelimeler: mikrobiyal pigment, gıda endüstrisi, biyolojik özellikleri

1. Introduction

Microalgae play an important role in the marine biological system. With their photosynthetic ability, they are the major producer of biomass and organic compounds in the oceans (Shimizu, 1993) and including the production of specialty compounds and nutritional supplements (Dunahay et al., 1996). Microalgae are a highly heterogeneous group of organisms and to be called a microalga, the organism to be small (usually microscopic), unicellular (but can be colonial with little or no cell differentiation), colourful (wherefore pigments), occur mostly in water and most likely be photoautotrophic. The microalgae, as a group, a potentially rich source of a vast array of chemical products with applications in the feed, food, nutritional, cosmetic, pharmaceutical and fuel industries (Schwartz et al., 1990; Kay and Barton, 1991; Borowitzka, 1992; Vilchez et al., 1997; Olaizola, 2003; Metzger and Largeau, 2005; Carvalho et al., 2006; Chisti, 2007; Chisti, 2008; Eriksen, 2008; Xu et al., 2009).

Live microalgae have been the traditional food for many animals in aquaculture. However, their mass cultivation on-site can represent 30% of a production cost (Coutteau and Sorgeloos, 1992; Knuckey et al., 2006). Alternatives that are potentially more cost-effective have been investigated including microcapsules, dried microalgae, yeasts or yeast-based diets and bacteria (Robert and Trintignac, 1997, Knauer and Southgate, 1999; Langdon and Onal, 1999; Knuckey et al., 2006).

Microalgae are tremendous valuable microorganisms because they are the light-harvesting "cell factories" that convert carbon dioxide into biomass or a variety of bioactive compounds. The all microalgae which many can grow heterotrophically but photoautotrophs, requiring mainly sun, water and inorganic nutrients for growth. Compared to higher plants, microalgae are simple in structure, being unicellular, filamentous or colonial, and energy is directed via photosynthesis into growth and reproduction (Walker et al., 2005; Xu et al., 2009).

The microalga species are capable of synthesizing all amino acids; they can provide the essential ones to humans and animals (Guil-Guerrero et al., 2004). However, to fully characterize the protein and determine the amino acid content of microalgae, information on the nutritive value of the protein and the degree of availability of amino acids should be given (Becker, 1988). Carbohydrates in microalgae can be found in the form of starch, glucose, sugars and other polysaccharides, and their overall digestibility is high, which is using dried whole microalgae in foods or feeds (Becker, 2004). The average lipid content of algal cells varies between 1% and 70% but can reach

90% of dry weight under certain conditions (Metting, 1996).

Table 1. General composition of different micro algae (% of dry matter)

Alga	Protein	Carbohydrates	Lipids
Anabaena cylindrica	43–56	25–30	4–7
Aphanizomenon flos-aquae	62	23	3
Chlamydomonas rheinhardii	48	17	21
Chlorella pyrenoidosa	57	26	2
Chlorella vulgaris	51–58	12–17	14–22
Dunaliella salina	57	32	6
Euglena gracilis	39–61	14–18	14–20
Porphyridium cruentum	28–39	40–57	9–14
Scenedesmus obliquus	50–56	10–17	12–14
Spirogyra sp.	6–20	33–64	11–21
Arthrospira maxima	60–71	13–16	6–7
Spirulina platensis	46–63	8–14	4–9
Synechococcus sp.	63	15	11

Algal lipids are composed of glycerol, sugars or bases esterified to saturated or unsaturated fatty acids (12 to 22 carbon atoms). Microalgae also represent a valuable source of almost all vitamins (e.g., A, B1, B2, B6, B12, C, E, nicotinate, biotin, folic acid and pantothenic acid) (Becker, 2004; Spolaore et al., 2006).

The algal biotechnology mainly connected to choosing the right alga with relevant properties form specific culture conditions and products (Table 2; Pulz and Gross, 2004).

1. Final Development Related Microbial Pigments

Natural pigments were the only source of colour available and were widely used and traded, providing a major source of wealth creation around the globe before the emergence of synthetic pigments. It has been used for purposes such as the colouring of natural fibres, fur and leather (Venil et al., 2013). The art of dyeing is of based on old and many of the dyes go back into prehistory.

Table 2. Microalga species with high relevance for biotechnological applications

Species/group	Product	Application areas	Basins/reactors
Spirulina platensis/Cyanobacteria	Phycocyanin, biomass	Health food, cosmetics	Open ponds natural lakes
Chlorella vulgaris/Chlorophyta	Biomass	Health food, food supplement, feed surrogates	Open ponds, basins, glass-tube PBR
Dunaliella salina/Chlorophyta	Carotenoids, β-carotene	Health food, food supplement, feed	Open ponds, lagoons
Haematococcus pluvialis/Chlorophyta	Carotenoids, astaxanthin	Health food, pharmaceuticals, feed additives	Open ponds, PBR
Odontella aurita/Bacillariophyta	Fatty acids	Pharmaceuticals, cosmetics, baby food	Open ponds
Porphyridium cruentum/Rhodophyta	Polysaccharides	Pharmaceuticals, cosmetics, nutrition	Tubular PBR
Isochrysis galbana/Chlorophyta	Fatty acids	Animal nutrition	Open ponds
Phaedactylum tricornutum/Bacillariophyta	Lipids, fatty acids	Nutrition, fuel production	Open ponds, basins
Lyngbya majuscule/Cyanobacteria	Immune modulators	Pharmaceuticals, nutrition	

* PBR – photo bioreactor

In Europe, it was applied to during the Bronze Age. The earliest written record of the use of natural dyes was found in China dated 2600 BC. In Indian subcontinent, dyeing was known as early as in the Indus Valley period (2500 BC) and has been substantiated by findings of coloured garments of cloth and traces of madder dye in the ruins of Mohenjo daro and Harappa civilization (3500 BC). In Egypt, mummies have been found wrapped in coloured cloth. Chemical tests of red fabrics found in the tomb of King Tutankhamen in Egypt showed the presence of alizarin, a pigment extracted from madder. The cochineal dye was used by the people of Aztec and Maya culture period of Central and North

America. The 4th century AD, dyes such as wood, madder, weld, Brazil wood, indigo and a dark reddish-purple were known. Brazil was named after the wood found there (Frankel, 1993; Aberoumand, 2011). Henna was used even before 2500 BC, (Freund et al., 1988; Aberoumand, 2011) while saffron is mentioned in the Bible (Frick & Meggos, 1988; Aberoumand, 2011). Use of natural bio colorants in food is known from Japan in the shoso in text of the Nara period (8^{th} century) contains references to coloured soybean and adzuki-bean cakes, so it appears that coloured processed foods had been taken at least by people of some sections. Study of colour intensified, since late 19th century (Aberoumand, 2011).

They were also used to colour cosmetic products and to produce inks, water colours and artist's paints (Cristea & Vilarem, 2006; Venil et al., 2013). Historical developments in colour were demonstrated in Table 3. Since the introduction of synthetic dyes by Perkin in 1856 (Joshi et al., 2003; Venil et al., 2013), many convenient and cheap synthetic pigments have appeared, and the use of natural dyes has decreased due to the relatively cheaper synthetic pigments (Zollinger, 1991; Venil et al., 2013). Throughout the 20th century, naturally occurring organic pigments have been almost completely displaced by synthetic molecules such as phthalocyanines that range from blue to green, aryl ides that are yellow to greenish or reddish-yellow and quinacridones ranging from orange to violet (Lomax & Learner, 2006; Venil et al., 2013). Advances in organic chemistry enabled mass production of these compounds relatively cheaper thereby allowing them to displace natural product pigments, whose procurement is often more challenging. Applications of synthetic pigments are in the textile industry, leather tanning industry, paper production, food technology, agricultural research, light harvesting arrays, photo electrochemical cells and in hair colourants (Venil et al., 2013).

The synthetic pigments are consistently decreased under pressure of new rules and from the consumers. Table 4 shows the natural pigments available in the world market (Durán et al., 2002). Nowadays there is a great interest of the market for the microbial pigments; because of widely used synthetic pigments have harmful issues associated with the workers of industry as well as consumer. The success of any pigment produced by fermentation depends upon its acceptability in the market, regulatory approval, and the size of the capital investment required bringing the product to market. Microbial pigments are not only used as food colorant, flavouring agent and dying agents they are widely applied in medicinal aspects. Apart from food and textile colouring

Table 3. Historical developments in colour

Year	Development
1886	Perkin's mauve pigment was discovered and coal tar dyes were synthesized
1884	*Monascus* sp. was traditionally cultivated and utilized in the orient for making red rice wine, red shao hsing wine and red Chinese rice
1954	The first carotenoid pigment from *Cryptococcus* was marketed
1963	Production of carotenoid pigments from *Rhodotorula* sp. started
Early 1970s	Astaxanthin was isolated from *Phaffia rhodozyma* (in honour of Prof. Herman Jan Phaff) grown on exudates of deciduous trees in Japan and Alaska
Late 1970s and early 1980s	Production of beta carotene from *Dunaliella salina* took place
1985	Betatene limited corporation was established for cultivation of *D. salina* on large scale for producing natural beta carotene products

they have been used in clinical therapy to lower the blood cholesterol concentration, e.g. Anti-Diabetic Activity, Anti-Inflammation. A few years ago, some expressed doubts about the successful commercialization of fermentation-derived food grade pigments because of the high capital investment requirements for fermentation facilities and the extensive and lengthy toxicity studies required by regulatory agencies. Public perception of biotechnology-derived products should also be taken into account. Some fermentative food grade pigments are in the market and also the algae-derived or vegetable extracted pigments are successful marketed (Kumar et al., 2015).

3. Microbial Pigments Obtained from Different Ecosystems

Microorganisms by produce food grade pigments like carotenoids, melanins, flavins, quinones, and more specifically monascins, violacein, indigo, etc. Fermentation derived ingredients in the food industry are increasing the year. Production of food grade pigments by microbial fermentation is at a developing stage (Clydesdale, 1993; Dharmaraj et al., 2009). Especially carotenoids are widely used as food colourants (Klaui, 1981) and pigments in feeds (Marusich & Bauernfeind, 1981; Simpson et al., 1981).

Table 4. Natural pigments available in the world market

Pigments	**CODE**[22]
YELLOW	
Curcumin	E 100
Riboflavin	E 101
Annatto (carotenoids)	E 160
Xathophills (cathaxenthines)	E 161
RED	
Carminic acid	E 120
Beetroot Red (betaine)	E 162
Anthocyanine	E 163
GREEN	
Chlorophylle	E 140
Chlorophyllins	E 141
Greee S	E 142
BROWN	
Caramel colour	E 150
Ammoniun sulfite caramel	E 150
BLACK	
Carbo medicinalis	E 153

More than 600 different carotenoids are synthesized by plants and microorganisms (Park et al., 2007). In addition to this, a number of microorganisms that includes *Serratia* and *Streptomyces* produce carotenoids in good amount (Kim, 1997; Dharmaraj et al., 2009). While the majority of microbes reported produce carotenoids constitutively, some organisms belonging to *Myxococcus* (Browning et al., 2003), *Streptomyces* (Takano et al., 2006), *Mycobacterium* (Rilling, 1962), *Agrobacterium* (Yokoyama & Miki, 1995) and *Sulfolobus* (Hemmi et al., 2003), form these pigments when the cells are illuminated. The two *Streptomyces* sp., *Streptomyces setonii* and *Streptomyces griseus* are designated as cryptic since the conditions for carotenoid production in these organisms are unknown (Kato et al., 1995; Schumann et al., 1996; Krügel et al., 1999).

The red pigment includes monascorubramine and rubropunctamine that are the nitrogen analogues of the orange pigment. The yellow pigment includes monascin and ankaflavin (Zhou et al., 2009). The stained marble was found to contain red-pigmented heterotrophic bacteria belonging to the genera *Micrococcus*, *Halococcus*, and *Flavobacterium*, as well as the red yeast *Rhodotorula minuta*, and some photosynthetic microorganisms (Konkol et al., 2009).

Nowadays some fermentative food grade pigments from filamentous fungi exist in the market: *Monascus* pigments, Arpink red™ from *Penicillium oxalicum*, riboflavin from *Ashbya gossypii*, lycopene and β-carotene from *Blakeslea trispora*. Fungal hydroxyanthraquinoid (HAQN) pigments are widespread in nature (plants, insects, lichens) and have also been found abundantly in microorganisms, particularly in filamentous fungi belonging to the genera *Penicillium* sp. and *Aspergillus* sp., with different colour hues (Dufosse´ et al., 2014). Some strains among *Talaromyces* species (formerly *Penicillium* sp.) viz. *Talaromyces aculeatus*, *T. funiculosus*, *T. pinophilus*, and *T. purpu*ro genus have been discovered to produce *Monascus* like polyketide azaphilone (MPA) pigments without coproducing citrinin or any other known mycotoxins using chemotaxonomic rationale (Teng & Feldheim, 2001; Dufossè et al., 2014).

Algae can be categorised into Chlorophyceae (green), Rhodophyceae (red), Pheophyceae (brown) according to their colours. Among the significant pigments produced by algae are chlorophyll a, b and c, ß- carotene, Astaxanthin, Phycocyanin, Xanthophyll and Phycoerythrin which are frequently used in food, pharmacology, textile and cosmetics (Anonymous, 2015). Traditionally natural pigments have been extracted from natural sources such as plant and insect tissues, but obtaining pigments through microbial fermentation is also possible. Some bacteria, yeasts, basidiomycetes fungi and microalgae are known to produce pigments (Arad and Yaron, 1992; Ogihara et al., 2001; Davoli and Weber, 2002; Ginka et al., 2004; Zhang et al., 2006; Mapari et al., 2008), but high costs and low productivity are significant bottlenecks for commercial production (Hejazi and Wijffels, 2004; Hailei et al., 2011). A natural pigment as Astaxanthin produced from microalgae is a strong bioactive material (Yeum & Russell, 2002). The red microalgae are characterized by their accessory pigments which are red or blue. The pigment list's obtained from microorganisms is given in Table 5 (Malik et al., 2012).

Table 5. List of pigment producing microorganisms.

Microorganism (s)	P igments/Molecule	Colour/appearance
Bacteria		
Agrobacterium aurantiacum	Astaxanthin	Pink- red
Paracoccus carotinifaciens	Astaxanthin	Pink-red
Bradyrhizobium sp.	Canthaxanthin	Dark- red
Flavobacterium sp., *Paracoccus zeaxanthinifaciens*	Zeaxanthin	Yellow
Achromobacter		Cream
Bacillus		Brown
Brevibacterium sp		Orange yellow
Corynebacterium michigannise		Greyish to creamish
Corynebacterium insidiosum	Indigoidine	Blue
Rugamonas rubra, Streptoverticillium rubrireticuli, Vibrio gaogenes, Alteromonas rubra	Prodigiosin	Red
Rhodococcus maris		Bluish- red
Xanthophyllomyces dendrorhous	Astaxanthin	Pink-red
Haloferax alexandrinus	Canthaxanthin	Dark- red
Staphylococcus aureus	Staphyloxanthin Zeaxanthin	Golden Yellow
Chromobacterium violaceum	Violacein	Purple
Serratia marcescens, Serratia rubidaea	Prodigiosin	Red
Pseudomonas aeruginosa	Pyocyanin	Blue-green
Xanthomonas oryzae	Xanthomonadin	Yellow
Janthinobacterium lividum	Violacein	Purple
Algae		
Dunaliella salina	β-carotene	Red
Chlorococcum	Lutein	
Hematococcus	Canthaxanthin	
Fungi		
Aspergillus sp.		Orange-red
Aspergillus galucus		Dark-red
Blakeslea trispora	β -carotene	Cream
Helminthosporium catenarium		Red
Helminthosporium avenae		Bronze
Penicilllum cyclopium		Orange
Penicilllum nalgeovensis		Yellow
Fusarium sporotrichioides	Lycopene	Red
Haematococcus pluvialis	Astaxanthin	Red
Monascus sp.	Monascorubramin Rubropunctatin	Red Orange
Monascus purpureus	Monascin Ankaflavin	Red Yellow
Monascus roseus	Canthaxanthin	Orange-Pink
Monascus sp.	Ankaflavin	Yellow
Penicillium oxalicum	Anthraquinone	Red
Blakeslea trispora	Lycopene	Red
Cordyceps unilateralis	Naphtoquinone	Deep blood-red
Ashbya gossypi	Riboflavin	Yellow
Mucor circinelloides, Neurospora crassa and *Phycomyces blakesleeanus*	β -carotene	Yellow-Orange
Penicillium purpurogenum, Paecilomyces sinclairii		Red
Pacilomyces farinosus	Anthraquinone	Red
Yeast		
Cryptococcus sp.		Red
Saccharomyces neoformans var. *nigricans*		Melanin black
Phaffia rhodozyma	Astaxanthin	Pink-red
Rhodotorula sp. *Rhodotorula glutinis*	Torularhodin	Orange-red
Yarrowia lipolytica		Brown
Actinomycetes		
Streptoverticillium rubrireticuli	Prodigiosin	Red
Streptomyces echinoruber	Rubrolone	Red

In addition, microalgae are preferred since they can be cultured easily and fast when mixed with plants and they are also demanded for their high rate of carotenoid production, high bio-compatibility and benefits (Turkcan & Okmen, 2012).

4. Antioxidant Activities of Microalga

Nowadays, there has been a surge in research on the potential role of antioxidants in the treatment of atherosclerosis, heart disease, liver disorders, neurodegenerative dysfunction, cancer, and diabetes mellitus (Madhavi et al., 1996; Finkel and Holbrook, 2000; Ajitha et al., 2001; Mukund, 2013). For this aim, the functional foods are widely preferred by consumers due to the functional ingredient from the traditional foods that possess ingredients which are able to provide a useful action for human health. These natural ingredients are chosen by consumers and usually extracted from natural sources (plants, food by-products or even algae and microalgae). Among many ingredients in natural sources, antioxidants compounds are being the most studied (Hadzri et al., 2014).

Antioxidants play an important role to protect the human body against oxidative damage caused by free radicals. Oxidative free radicals are highly reactive to attack molecules by capturing electrons and thus modifying chemical structures. The free radicals are generated through the oxidation of carbohydrates, fats and proteins through both aerobic and anaerobic processes. Over-production of the free radicals is responsible for tissue injury (Gomathi et al. 2013; Kalidasan et al., 2015). Some algae are noted as rich sources of natural antioxidants (Chkhikvishvili & Ramazanov, 2000; Huang & Wang, 2004). Algae contains many biotic compounds such as phenolic compounds, alkaloids, plants acid, terpenoides and glycosides and they are used as antioxidants, anti-bacterial, antiviral and anti-carcinogenic (Demirel et al., 2009; Ansari and Nikhil, 2014). Polyphenolic compounds are among the interesting antioxidant compounds isolated from marine resources, including micro and microalgae. The most polyphenols isolated from marine sources and referenced in the literature are of macro and microalga origin (Amann et al., 1991). The intensity of the antioxidant activity of these complex polyphenols is related to the degree of polymerization of the polyphenol. Algal biomass and algae-derived compounds have a very wide range of potential applications, from animal feed and aquaculture to human nutrition and health products. There has been very limited information on antioxidant activity of microalgae (Herrero et al., 2005; Murthy et al., 2005; Tannin-Spitz et al., 2005). The microalga cells can be controlled, so that some of these contain no herbicides and pesticides, or any other toxic substances, by using clean nutrient media for growing the microalgae (Li & Chen, 2001; Li et al., 2002). The value of microalgae as a source of natural antioxidants is further enhanced by the relative ease of purification of target compounds (Li et al., 2001; Li et al., 2007). Some of the seaweeds are considered to be a rich source of antioxidants (Lim et al., 2002). For example, chlorophylls, carotenoids, tocopherol derivatives such as vitamin E, and related isoprenoids that are structurally related to plant-derived antioxidants were found in some marine organisms (Takamatsu et al., 2003; Duan et al. 2006). In addition to fruits and vegetables, the carotenoids from microalgae have also demonstrated antioxidant properties (Jahnke, 1999; Maoka, 2011). Carotenoids possess other bioactivities and are thought to be active agents for the prevention of cancer cardiovascular diseases, and macular degeneration (Stierle et al., 1988; Balakrishnan et al., 2014). Seaweeds are considered to be an important source of bioactive compounds, as they are able to produce a great variety of secondary metabolites characterized by a broad spectrum of biological activities. Compounds with cytostatic, antiviral, anthelminthic, antifungal, and antibacterial activities have been detected in green, brown and red algae (Newmann et al., 2003; Ambreen et al., 2012; Yildiz et al., 2014). *Spirulina* boost the immune system and enhance the body's ability to generate new blood cells to prevent disease and cancer (Mathew et al. 1995; Danaraddi, et al., 2016).

The pigments, phenolics, antioxidant and vitamins from microalgae are given in Table 6 (de Jesus Raposo and de Morais, 2015). Especially carotenoids in general, and those from marine microalgae in particular, are excellent antioxidants, which can be exogenously supplied to the cells. Some of the most known and studied carotenoids produced by microalgae include β-carotene from *Dunaliella salina*, astaxanthin from *Haematococcus pluvialis*, canthaxanthin from *Coelastrella striolata*, but also the less known, but not less effective, fucoxanthin from several diatoms, such as *Phaeodactylum tricornutum*, and *Isochrysis galbana (*Gross et al., 2002; Bhatt, 2008; Helmersson et al., 2009; Riccioni, 2009; Fassett et al., 2011; Bian et al., 2012; Speranza et al., 2012; de Jesus Raposo and de Morais, 2015).

5. The Application in Food Industry

Colour is a vital quality attribute of foods, and plays an important role in sensory and consumer acceptance of products that consumers assess when determining the quality and appearance of a product, and therefore conditions its acceptability (Fernández-García et al., 2012). Based on the origin, food colours can be classified as natural, nature identical and synthetic. The use of colour in food has been a common practice since ancient time. With globalization in the research trends, colorants have been used for many years in the pharmaceutical industry in order to add colour to many medicinal products, as well as to ensure the same colour for all the batches of a given product (Rowe et al., 2003; Sanjay et al., 2007). Colours of foods create physiological and psychological expectations and attitudes that are developed by experience, tradition, education and environment (Stich et al., 2002; Dharmaraj et al., 2009). Natural pigments which are often commercially available in powder, oil-soluble emulsion, or water-soluble emulsion forms (Caro et al., 2012) and synthetic are used extensively in the food, cosmetic and pharmaceutical industries (Mapari et al., 2005).

Concerns over potential toxicity of some synthetic pigments have led to increased interest in pigments derived from natural sources (Downham & Collins, 2000; Mapari et al., 2005; Silveira et al., 2008; Hailei et al., 2011). Natural colorants or dyes derived from flora and fauna are believed to be safe because of non-toxic, non-carcinogenic and biodegradable in nature. Therefore the present trend throughout the world is shifting towards the use of eco-friendly and biodegradable commodities, the demand for natural colorants are increasing day by day. Natural pigments are sourced from ores, insects, plants and microbes. Among microbes, bacteria have immense potential to produce diverse bio-products and one such bio-product is pigments (Venil et al., 2013). Some bacteria, yeasts, basidiomycetes fungi and microalgae are known to produce pigments (Ginka et al., 2004; Zhang et al., 2006; Mapari et al., 2008), but high costs and low productivity are significant bottlenecks for commercial production (Hejazi & Wijffels, 2004).

Ascomycetes fungi of the genus *Monascus* have been used to produce a natural food colorant when grown on rice (Liu et al., 2005); however, *Monascus* derived pigments contain citrinin, and the production of mycotoxin limits the use of *Monascus* as a producer of food colorants (Liu et al., 2005; Hailei et al., 2011). Some species of the genus *Monascus* have long been used in East Asia as a natural food colorant for red rice wines, red soybean cheeses, and meat and fish products. Typical *Monascus* pigments are red, orange and yellow (Kim et al., 2006). Basidiomycete fungi may produce melanin from phenols and catechol precursors, characterized by a dark brown colour, in contrast to the true black appearance of melanin from the polyketide monomer 1.8 dihydroxynaphthalene (DHN) (Tudor et al., 2013). A natural pigment, Astaxanthin, produced from microalgae is a strong bioactive material and frequently used to be supplementary food to give more yellowish colour to egg's core and antioxidant in food (Yeum & Russell, 2002).

Nowadays, fermentative production of food-grade pigments particularly carotenoids from microorganisms are available in the market. To name a few, pigments from *Monascus* sp. (Blanc et al., 1994; Fabre et al., 1993; Hajjaj et al., 1999), astaxanthin from *Xanthophyllomyces dendrorhous* (Cruz & Parajo, 1998; An et al., 2001; Johnson & An, 2008), Arpink red colour from *Penicillium oxalicum* (Sardaryan, 2002; Sardaryan et al., 2004), riboflavin from *Ashbya gossypii* (Jacobson & Wasileski, 1994; Stahmann et al., 2000; Santos et al., 2005;),β-carotene from *Blakeslea trispora* (Lampila et al., 1985; European Commission, 2000; Enrique et al., 2005) and lycopene from *Erwinia uredovora* and *Fusarium sporotrichioides* (Jones et al., 2004; Leathers et al., 2004). In addition to this, a number of microorganisms that includes *Serratia* and *Streptomyces* produce carotenoids in good amount (Kim et al., 1997; Dharmaraj et al., 2009).

Table 6. Pigments, phenolics and antioxidant vitamins from microalgae

Phytochemicals	Microalgae	Concentration	References
	Dunaliella salina	10–13% DW	El-Baz et al. (2002)
Carotenoids	*Chlorella zofingiensis*	50% total carotenoids	Bar et al. (1995)
β-carotene	*Arthrospira*	80% total carotenoids	Patel et al. (2005); Miranda et al. (1998)
Astaxanthin	*H. pluvialis*	Up to 4% DW	Steinbrenner and Hartmut (2001)
	Arthrospira		El-Baky et al. (2003)
Canthaxanthin	*C. zofingiensis*	25% total carotenoids	Bar et al. (1995)
	Arthrospira		El-Baky et al. (2003)
Lutein			
Phycobiliproteins			
C-phycocyanin	*Arthrospira*	Up to 20% DW	Sarada et al. (1999); Patel et al. (2005)
Phycoerythrin	*Porphyridium*	80% total phycobiliproteins	Rebolloso-Fuentes et al. (2000)
Phenolics (acids)			
Synapic	*Arthrospira*		Miranda et al. (1998)
Gallic	*Phaeodactylum*		Goiris et al. (2012)
trans-Cinnamic	*Tetraselmis Chlorella*		
Chlorogenic	*Neochloris, Isochrysis*		
Quimic	*Botryococcus*		
Caffeic			
Antioxidant vitamins			
Vitamin E	*Dunaliella*	12.1 mg/L	El-Baz et al. (2002)
(α-tocopherol) D	*Haslea, Chlorella*		
	D. tertiolecta	116.3 mg/kg DW	Miranda et al. (1998)
	T. suecica	442 mg/kg DW	Fabregas and Herrero (1990)
Vitamin C	*Isochrysis*	885 mg/kg DW	Bandarra et al. (2003) El-Baz et al. (2002)
(ascorbic acid)	*Dunaliella*	24.6 mg/L	
	P. cruentum		Sarrobert and Dermoun (1991)
	D. tertiolecta	163.2 mg/kg	
	T. suecica	191.0 mg/kg DW	
Other vitamins: Provitamin A	*P. cruentum*		Sarrobert and Dermoun (1991)
	D. salina		El-Baz et al. (2002)
B complex: thiamine, riboflavin, pyridoxine, folic acid, (cyano) cobalamin	*Dunaliella, Chlorella*		Fabregas and Herrero (1990)

An overview of the most important elements, which need to be considered to enable successful production and application of food commodities from microalgae, is showed in Fig. 1 (Draaisma et al., 2013).

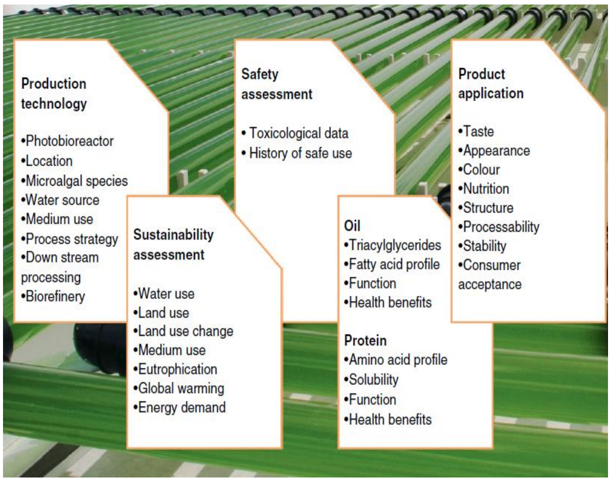

Fig. 1. Food commodities from microalgae: overview of key features, which need to be considered to enable successful sustainable, cost effective and safe product applications.

The orange pigment includes monascorubrin and rubropunctatin, possessing the oxo-lactone ring. The red pigment includes monascorubramine and rubropunctamine that are the nitrogen analogues of the orange pigment. The yellow pigment includes monascin and ankaflavin (Zhou et al., 2009). Among these pigments, the red pigment (monascorubramine and rubropunctamine) is of high demand, especially for its use in meat products to substitute nitrites (Fabre et al., 1993). The red pigment is also reported to have the potential for therapeutic use particularly when produced in red rice (Lin et al., 2008; Mukherjee and Singh, 2011). While Rommier (1868) studied its dyeing properties on silk and wool, most recent studies determined that xylindein inhibits plant germination without any hazardous effects on cultivated crops (Shibata et al., 2007; Tudor et al., 2013).

6. Conclusions

As food colourants are bio-accessibility of bioactive compounds that are of interest to the food scientists, nutritionists and food industries due to their positive impact on human health and their economic benefits. However, the number of approved colourant for food industry is limited. In addition the need for the studies related to the activities and contents of microbial pigments obtained from different ecosystems increases consistently. It is also thought that the studies related especially to pigments to be used as colourants in food and additive materials can contribute greatly to the subject. While the use of microalgae in functional foods and animal feed could soon reach the level of mass products, their use in pharmaceutical applications appears to lie more in the future.

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