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Chapter

Introductory Chapter: Overview of New Perspectives and Applications of Carotenoids

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1. Introduction

Carotenoids are naturally occurring terpenoid pigments made of isoprene residues, displaying a conjugated double polyene chain. They are hydrophobic compounds and are usually formed by a skeleton of 40 hydrocarbons, although most of the derivatives present in extremophilic microbes like those belonging to the Archaea domain contain 50 carbon atoms. This chain can be terminated by rings or functional groups with oxygen [1]. These compounds can absorb light mainly in the range of 300–600 nm (they show colors that vary from yellow to red) and are responsible for the characteristic pigmentation shown by some flowers, fungi, and several microorganisms. The ability to absorb light at a certain wavelength is related to the number of functional groups and double bonds present in their structure [2]. They are also involved in many biological roles in all living beings, reporting beneficial actions.

To date, over 1100 natural carotenoids have been described in animals, plants, macroalgae, some fungi, and a wide variety of microorganisms (including extremophiles). Due to the structural diversity of these molecules, there are still several biochemical and physiological functions to be associated with this class of compounds. Accordingly, these characteristics enable wide applicability, which drives the global carotenoid market.

Carotenoids are beneficial for human health; however, humans cannot synthesize carotenoids de novo, consequently, they are mainly obtained through the diet. In fact, carotenoids are consistently found in tissues or biological fluids, where they play a beneficial role in decreasing the risk of developing some diseases, such as cancer, eye disorders, and autoimmune or cardiovascular diseases.

During the last half-century, significant advances in the research of carotenoids have been made. As an example, much knowledge on their biosynthesis in plants and microbes has been generated, and there have been important breakthroughs in their production in both conventional and genetically modified organisms, not only in the laboratory but also on a large scale [3, 4].

The aim of this book is to highlight new perspectives and applications of carotenoids, including characterization and isolation of new compounds (including rare carotenoids), their production at a mid-large scale (involving new innovative approaches), and uses of carotenoids in different biotechnological fields, such as food science, biomedicine, and cosmetics.
2. Current research on carotenoids

Most of the recent studies on carotenoids describe the importance, chemical composition, and functioning of carotenoids. Although the research is mainly paying attention to C\textsubscript{40} carotenoids, the interest in rare carotenoids, such as marine C\textsubscript{50}, is increasing due to their significant antioxidant activity [3, 5].

There is also an important research field in which efforts are focused on looking for new natural sources from which natural carotenoids can be isolated. Considering their biological roles (not fully described yet), the potential applications of these molecules are still increasing. Some of the better described biological roles of carotenoids in plants, animals, and microbes are given below:

- Light absorbance mechanisms during photosynthesis.

- Protection of chlorophyll molecules and other cellular structures (not only in plants but also in animals, fungi, and microorganisms) from oxidative stress and reactive oxygen species (ROS) damage.

- Cellular signaling in plants: responses to environmental stresses, pollination, germination and reproduction, and development regulation.

- Strong antioxidant activity is primarily linked to their polyene molecular structure. Thus, carotenoids are reported as immune-enhancement and anticancer agents, which are also involved in the prevention of eye-, gastric and neurocognitive disorders, and in the regulation of obesity and anti-aging.

- Hormone precursors and precursors of vitamin A.

Among carotenoids, β-carotenes, astaxanthin, canthaxanthin, and lutein are highly marketed because they are part of drugs and cosmetics formulas or can be added to food due to their color or their antioxidant activities. So far, the large-scale production and subsequent commercialization of these compounds are carried out through chemical production, which has advantages and disadvantages compared to natural production. Thus, carotenoids chemically produced are characterized by excellent purity and consistency, with a relatively low production cost. However, the chemical synthesis of carotenoids involves the use of reagents, which are not environmentally friendly. Besides, the synthesis of pigments of greater structural complexity is expensive and highly time consuming. Considering all these disadvantages, the production of natural pigments using cell factories reveals a promising approach to obtaining carotenoids on a large scale [6]. In fact, carotenoids productions based on cell factories and environmentally friendly procedures is one of the fields of research attracting more attention worldwide during the last decade.

Recently, several works stated that carotenoids are also interested in sustainable energy and green electronics, which sheds light on more potential applications for these natural compounds [7].

3. Challenges related to carotenoid research and applications

Considerable progress in carotenoid research has been made to understand the carotenoid metabolism in all life forms, including humans. However, despite
the extensive use of carotenoids in agri-foods sectors as well as in pharmaceutical industries, these pigments are an excellent example of poor understanding of food structure, the complexity of behavior during their digestion by animals, and interindividual differences in response, which lead to misinterpretation of study results. Consequently, there are a few challenges associated with understanding and measuring carotenoid bioavailability, which should be the aim of research during the next few years. Some of the most relevant challenges are following, which are grouped into two categories—challenges related to the use of carotenoids to promote positive effects on human health and challenges related to the production of natural carotenoids at a large scale by environmentally friendly procedures:

Carotenoids and human health [8]:

i. To improve the knowledge about molecular mechanisms involved in the release of carotenoids from food structure and processing into an absorbable form (bioaccessibility). Recently, technologies of micro- and nanoencapsulation have addressed the needs of carotenoid entrapping to enhance their bioavailability, solubility, and chemical stability, thus ensuring the target delivery and the maintenance of their strong antioxidant among other biological activities [9].

ii. To characterize the transport and mobilization mechanisms of carotenoids from the gut lumen into the body (absorption). Absorption studies are best carried out by measuring chylomicron carotenoid excursion, with modeling of chylomicron turnover rate. In this way, inter-individual differences in lipoprotein metabolism could be considered before formulating conclusions on the rate and extent of absorption.

iii. Monitoring and interpreting plasma responses because of carotenoid digestion.

iv. To understand how inter-individual variation determines the final effect of carotenoid ingestion. Metabolomics and metabonomics reveal powerful tools to address this issue as well as those summarized in points ii) and iii) [10].

Production of natural carotenoids at a large scale by environmentally friendly procedures [11]:

i. To design sustainable, cheaper, and environmentally friendly protocols, which produce natural carotenoids at a large scale. This mostly refers to the need for the identification and cloning of genes responsible for carotenoid biosynthesis and transformation and related development of transgenic carotenoid-rich microorganisms or crops.

ii. Among standard and some advanced analytic tools for carotenoid isolation and characterization (e.g., high-performance liquid chromatography – HPLC, liquid chromatography–mass spectrometry – LC–MS, ultra-high-performance liquid chromatography – UHPLC, high-performance thin-layer chromatography – HPTLC, and others), nuclear magnetic resonance (NMR), Fourier-transform infrared spectroscopy (FTIR), or the primarily Raman spectroscopy coupled with chemometric modeling, opened a new era in carotenoid research and application. However, studies based on those techniques are still scarce.
Finally, one of the most challenging issues is the extraction of carotenoids from natural sources. So far, several extraction methods have been employed for the extraction of carotenoids—solvent extraction, Soxhlet extraction, centrifugation, and non-conventional methods of extraction, such as ultrasound-assisted, microwave-assisted, enzymatic, and the innovative technique supercritical carbon dioxide (SC–CO$_2$) extraction.

However, apart from SC–CO$_2$ extraction, which extracts pure compounds in high yield without the use of harmful organic solvents, the other mentioned approaches (which are the most efficient procedures to isolate pure carotenoids at high yield) are characterized by the use of large amounts of organic solvents. Consequently, green technology for carotenoid extraction is still the need of the present time to guarantee the production of marketed carotenoids for keeping safe the environmental quality for the next generations.

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Conflict of interest

The author declares no conflict of interest.
References


