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NATURE'S CHROMATIC PALETTE - EXPLORING THE SPECTRUM OF CAROTENOIDS IN FRUITS, VEGETABLES, AND MICROBES FOR HEALTH AND WELLNESS: A REVIEW

Pooja Pandey[1], Chandrakala L[1], Monalisha M[1] & S Anu Kiruthika[2]

Department of Microbiology, Indian Academy Degree College - Autonomous, Hennur, Bengaluru

[1] M. Sc Microbiology students, Department of Life Science, Indian Academy Degree College - Autonomous, Bengaluru.

[2] Corresponding author: Dr. S Anu Kiruthika, Associate Professor in Microbiology, Department of Life Science, Indian Academy Degree College - Autonomous, Bengaluru.

ABSTRACT

Carotenoids, a diverse group of over 700 fat-soluble compounds, are responsible for the vibrant yellow, red, and orange pigments observed in plants, fruits, vegetables, algae, and photosynthetic bacteria. With a staggering assortment of more than 600 types, among which the well-known members of this pigment family are alpha-carotene, beta-carotene, beta-cryptoxanthin, lutein, zeaxanthin, and lycopene. This study aimed to isolate carotenoid-rich microbes from various fruits and vegetables using shadow drying followed by powder formation. Different extraction methods, including the traditional approach, as well as innovative techniques like USAE and MWAE, were employed to extract carotenoids from the microbial samples. The confirmation of successful carotenoid extraction was achieved through the utilization of the sophisticated HPLC technique. The carotenoids were classified into two main groups: xanthophylls and carotenes. Both groups exhibited antioxidant properties, contributing to their potential health benefits. Additionally, certain carotenoids possess the remarkable ability to be converted into vitamin A, a vital nutrient crucial for human growth and overall well-being. These carotenoids, known as provitamin A compounds, namely alpha-carotene, beta-carotene, and beta-cryptoxanthin, fall under this category. Alongside these, non-provitamin carotenoids like lutein, zeaxanthin, and lycopene offer their own distinctive human health benefits. Various fruits and vegetables rich in carotenoids include yams, kale, spinach, watermelon, cantaloupe, bell peppers, tomatoes, carrots, mangoes, and oranges. Understanding the composition and concentration of carotenoids in fruits and vegetables can contribute to improved dietary recommendations.

KEYWORDS

Pigment-producing microorganisms, fruits, vegetables, carotenoids, USAE, MWAE, HPLC, and GCMS.

OBJECTIVE

To explore the diverse spectrum of carotenoids, present in fruits, vegetables, and microbes, with a focus on their potential health and wellness benefits. By investigating the variations and compositions of carotenoids in different sources, the study aims to elucidate their roles in promoting human health, understanding their bioavailability, and assessing their potential applications in preventive and therapeutic interventions. Furthermore, the research aims to uncover novel insights into the biosynthesis, regulation, and metabolic pathways of carotenoids in various organisms, contributing to the broader understanding of these natural pigments and their significance in the context of nutrition, disease prevention, and overall well-being.

INTRODUCTION

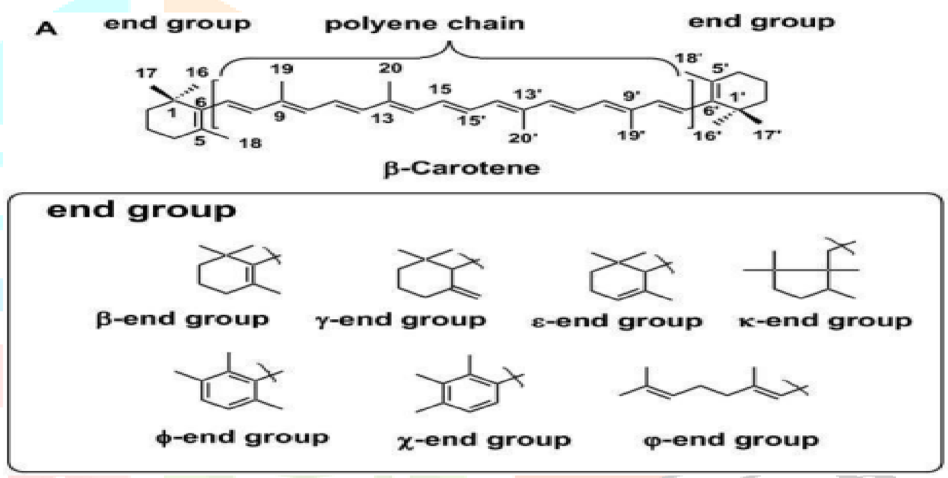
Carotenoids are widely distributed pigments that naturally display red, orange, and yellow colours. They are found in various fruits, vegetables, fungi, flowers, and certain animal *species* (Tles & Cagindi, 2008). While photosynthetic bacteria, algae, fungi, and plants can synthesize carotenoids through biosynthesis, humans and animal cells rely on obtaining carotenoids such as lutein, zeaxanthin, and astaxanthin from their diet (Ellison, 2016; Kaczor *et al.*, 2016). Carotenoids serve multiple beneficial effects, including attracting insect pollinators to flowers, indicating fruit ripeness, absorbing visible light for photosynthesis, and protecting cells from light-induced damage in photosynthetic bacteria, algae, and plants (Lerfall, 2016).

Furthermore, carotenoids play a crucial role in human health. For instance, lutein and zeaxanthin found in human eyes help filter out high-energy blue light, reducing oxidative stress on the retina (Roberts *et al.*, 2009). Additionally, certain carotenoids act as pro-vitamin A and antioxidants, offering various health benefits. The pharmaceutical and nutraceutical industries have utilized carotenoids for their advantageous properties (Tles and Cagindi, 2008; Alcaino *et al.*, 2016). Moreover, different carotenoids are used as food colorants in various food-related industries, replacing synthetic alternatives. In photosynthetic organisms, carotenoids serve as integral components of the light-harvesting antenna complex during photosynthesis and act as precursors for the hormone abscisic acid in higher plants. Some commercially used carotenoid pigments include β-carotene, astaxanthin, and canthaxanthin, which are employed as food colorants and animal feed additives in poultry farming and aquaculture. In recent times, certain carotenoids like astaxanthin, β-cryptoxanthin, lutein, zeaxanthin, and lycopene have gained attention for their beneficial effects on human health, including prevention of chronic diseases such as cancer, cardiovascular disease, and age-related macular degeneration. Consequently, these carotenoids have been used as nutraceuticals in the pharmaceutical and cosmetic industries.

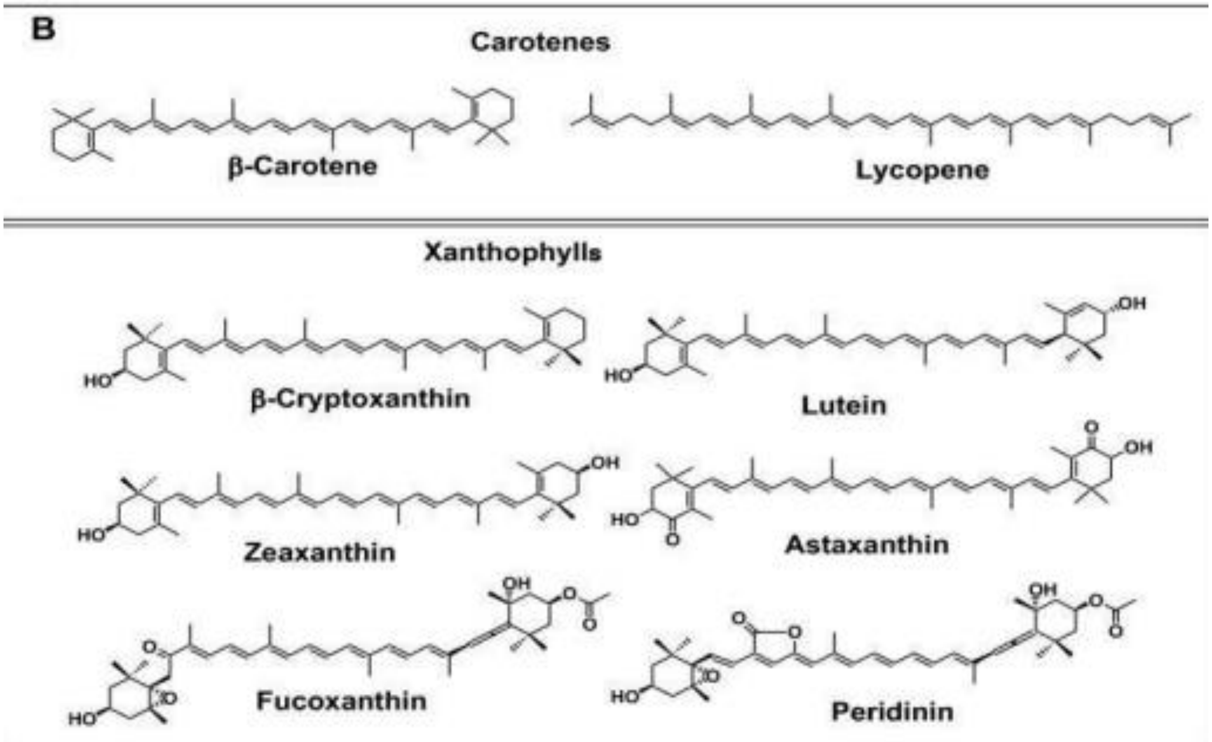
Carotenoid pigments can be classified as xanthophylls (carotenoids containing oxygen) or carotenes (hydrocarbon carotenoids) based on their chemical composition. The hydrocarbon phytoene (or 4,4'-diapophytoene in some cases) serves as the starting material for the biosynthesis of all carotenoids. Through various enzymatic processes, two molecules of geranylgeranyl diphosphate (GGPP) and farnesyl diphosphate (FPP) produce two molecules of phytoene and 4,4'-diapophytoene. These hydrocarbon precursors undergo dehydrogenation, conjugated double bond formation, cyclization, and other modifications, resulting in a wide range of xanthophylls. Thus, xanthophylls, derived from a limited number of carotenes, contribute significantly to the structural diversity of carotenoids. This is in contrast to other terpenes, such as sesquiterpenes, diterpenes, and triterpenes, where diverse cyclic terpenes with distinct structural variations are synthesized from FPP, GGPP, and 2,3-oxidosqualene, respectively, and involve chemically active oxygen atoms and further modification reactions (Norihiko Misawa, 2010).

OCCURRENCE

Carotenoids, derived from the Latin word "carota" meaning carrot, are remarkable compounds found in various photosynthetic organisms. They serve as photoprotective agents, antioxidants, and light-absorbing pigments. Carotenoids are synthesized from isopentenyl pyrophosphate (IPP), derived from the cytosolic mevalonic acid (MVA) pathway and the plastid methylerythritol 4-phosphate (MEP) pathway. These pathways converge to form geranylgeranyl pyrophosphate (GGPP), a key building block for carotenoid biosynthesis. Under the influence of enzymes like phytoene synthase (PSY), GGPP condenses to form 15-cis-phytoene, which acts as the starting point for the production of various carotenoid structures. Xanthophylls, a subclass of carotenoids, contain oxygen-containing groups, giving them greater polarity compared to hydrocarbon-based carotenes. Common xanthophylls include lutein, antheraxanthin, neoxanthin, violaxanthin, and zeaxanthin. Exploring the biosynthetic pathways and structural diversity of carotenoids offers insights into their potential applications in nutrition, health, and industry. Continuous research advancements in carotenoids hold promise for uncovering their multifaceted roles and facilitating the development of innovative solutions harnessing their unique properties.



A. Basic structure of carotenoids and end groups (Antonio J. Meléndez-Martínez *et al.,* 2021)



B. Structures of typical carotenes and xanthophylls (Antonio J. Meléndez-Martínez *et al.,* 2021)

Britton and Khachik (2009) have classified carotenoid patterns based on the color of plant tissue, proposing five distinct patterns:

a) The first pattern is characterized by a high concentration of acyclic carotene lycopene, which imparts a red colour to tissues, as seen in tomatoes.

b) The second pattern involves significant amounts of β-carotene and/or its hydroxyl derivatives β-cryptoxanthin and zeaxanthin, resulting in an orange colour.

c) Similar to pattern 2, the third pattern includes α-carotene and/or its hydroxyl derivatives, particularly lutein, contributing to a yellow-orange colour.

d) The fourth pattern is characterized by the presence of carotenoid epoxides, leading to a yellow colour.

e) The fifth pattern involves carotenoids that are unique to or characteristic of a particular species, contributing to yellow, orange, or red colours. Examples include capsanthin and capsorubin in red peppers and crocetin in saffron.

The study embraced a comprehensive arsenal of methods and methodology to delve into the diverse realm of carotenoids within fruits, vegetables, and microbes, with a particular lens on their implications for well-being.

METHODICAL APPROACHES

1. **Varied Sampling:** A rich assortment of fruits, vegetables, and microbial cultures were meticulously assembled, encapsulating a broad gamut of carotenoid origins.

2. **Analytical Precision:** Leveraging High-Performance Liquid Chromatography (HPLC), the research accurately parsed and quantified carotenoids within samples, enabling precise identification and measurement of the multifarious carotenoid compounds.

3. **Innovative Extraction Strategies:** Carotenoids were meticulously extracted from samples through solvent-based methods. Ethanol and hexane were handpicked for their low ecological impact. Advanced methodologies like Supercritical Fluid Extraction (SC-CO2) and enzyme-based extraction were also scrutinized for their efficacy and environmental credentials.

4. **Preservation Through Encapsulation:** Swift post-extraction encapsulation emerged as the guardian of carotenoids, shielding them from deterioration. This safeguarding mechanism augmented the resilience of the isolated carotenoids.

STRATEGIC METHODOLOGY

1. **Interdisciplinary Dive:** The study orchestrated an interdisciplinary methodology, pooling expertise from diverse fields encompassing chemistry, biology, and nutrition. This holistic foray unearthed the expansive facets of carotenoid diversity and functionality.

2. **Optimized Extraction Yield:** The response surface methodology was harnessed to finetune extraction parameters, a calculated maneuver to maximize carotenoid yield from the samples.

3. **Insightful Data Deconstruction:** The amassed data from HPLC analyses, extraction methods, and encapsulation protocols underwent meticulous statistical dissection. This analytical scrutiny spawned cogent deductions about carotenoid content and caliber.

4. **Benchmarking Efficacy:** A comparative analysis was orchestrated, affording an assessment of distinct extraction techniques on the yardsticks of yield, product excellence, and ecological resonance.

By synergizing these strategic methods and methodology, the study aspired to unfurl a comprehensive panorama of carotenoid composition in natural reservoirs. This ambitious venture sought to unravel the latent potential of carotenoids in championing health and well-being.

RECENT STUDIES

Investigating carotenoid profiles by analyzing the composition and concentration of these pigments in fruits, vegetables, and microbial sources, utilizing techniques like HPLC and spectrophotometry to identify and quantify specific carotenoids.

Conducting bioavailability studies to understand how carotenoids are absorbed and utilized by the human body, considering factors such as food matrix, processing methods, and individual variations in metabolism.

Exploring the mechanisms of action behind carotenoids' potential health benefits, including their antioxidant and anti-inflammatory properties, and their impact on various physiological processes.

Examining the role of carotenoids in preventing and managing chronic diseases such as cardiovascular disease, cancer, age-related macular degeneration, and neurodegenerative disorders, investigating specific carotenoids and their mechanisms of protection.

Developing nutraceutical products and functional foods by formulating and optimizing delivery systems to enhance the stability and bioavailability of carotenoids, and exploring their incorporation into food products to promote overall health and wellness. Studying microbial sources and employing genetic engineering techniques to enhance carotenoid production and optimize their profiles, aiming to develop sustainable and cost-effective microbial platforms for carotenoid production with desired properties.

Assessing the safety and regulatory considerations associated with the use of carotenoids in food and nutraceutical products, including determining appropriate dosages, evaluating potential adverse effects, and establishing guidelines for their consumption. (El-Sayed M. Abdel-Aal *et.al.*, 2013).

CONCLUSION

Still a mysterious class of natural colours, carotenoids, they play essential functional roles in biology in addition to being responsible for a wide variety of colours in nature. Studies on the role of carotenoids in human health and disease have all too frequently concentrated only on what might be considered a search for a "magic bullet" effect, i.e., a specific carotenoid (for example, -carotene) is found in "healthy" diets and because it is an antioxidant (at least in vitro), it is assumed that high doses must have a beneficial effect. Unfortunately, it has been demonstrated far too frequently that this strategy is overly simple, since it disregards the interactions with other dietary components (including other antioxidants) and the destiny of the antioxidants themselves, in particular when present in huge quantities. While some researchers have always taken into account some of these factors, such as Truscott and Edge, we are now witnessing a large number of studies tackling these intricate and technically difficult difficulties.

Moreover, carotenoids contribute to the enhancement of skin health, providing natural sun protection and promoting a youthful appearance. Some carotenoids, such as beta-carotene, are also precursors to vitamin A, a crucial nutrient for vision, growth, and immune function. By including a diverse range of colorful fruits and vegetables in our diets, we can ensure a sufficient intake of carotenoids to support overall health and wellness.

Interestingly, the world of carotenoids extends beyond the plant kingdom, as certain microbes also produce these pigments. Exploring the carotenoid profiles of microorganisms opens up new possibilities for their application in the food, pharmaceutical, and cosmetics industries. Microbial carotenoids exhibit unique structures and functions, offering potential as natural food colorants, antioxidants, and even therapeutic agents.

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