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Carotenoids

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Summary: This short review intends to present some key facts on carotenoids in a popular scientific language on the occasion of the International Year of Chemistry. Carotenoids have a characteristic $C_{40}H_{56}$ structure and represent a market value of several hundred million Euros. Their chemical synthesis is still a demanding challenge for chemists. Health claims for several carotenoids are summarised and results of epidemiological studies are discussed.

Keywords: Anti-oxidative effect · Carotenoids · Natural colourant · Provitamin A · Xanthophylls

1. Introduction

In a search you will get numerous hits for the keyword 'carotenoids' from independent sources and from manufacturers. This short review intends to present some key facts in a popular scientific language on the occasion of the International Year of Chemistry.

Carotenoids are the pigments that give colour to egg yolks, fungi, all green leaves, fruits and flowers (Fig. 1). They accumulate in crustaceans, certain fish species, feathers and insects. Carotenoids are a family of more than 600 naturally occurring pigments synthesised by plants, algae and photosynthetic bacteria but not by animals and mankind. The main colour tints are yellow, orange and red. Fruits and vegetables provide most of the carotenoids in the human diet. They are also found in dark green vegetables. The carotenoids of these vegetables have the important antioxidant function of quenching free oxygen radicals, oxidants formed during photosynthesis. This deactivation of free radicals is vital for photosynthetic active plants. Carotenoidless mutants of green plants are not viable in sunlight.

2. Health Claims for Carotenoids

The most popular function of carotenoids is their use as natural colourants and stabilising agents. Foods that contain carotenoids retain their appearance for long periods and withstand the action of direct sunlight. There are numerous applications in food colouring, for beverages but also confectionery, dairy and bakery products.

Principally the scavenger activity for oxygen radicals should be the same as in humans as in plants. In recent years a tremendous amount of attention was given to carotenoids as potential anticancer and anti-aging compounds. *In vitro* studies indeed prove that carotenoids inhibit the oxidation of fats. A reduced risk of lung cancer was found in epidemiological studies with high beta carotene intake. However studies of supplementation with large doses of beta carotene in smokers have shown an increase of lung cancer risk. Scientifically neither the negative effects in the smoker study nor the beneficial effects in non-smoker studies could be properly explained. Overall a protective effect of dietary carotenoids based on its anti-oxidative effect against the development of cancers is believed to be likely. Beta carotene together with vitamin E and vitamin C forms the trio of antioxidant vitamins now believed to have a preventive effect on degenerative diseases such as cardiovascular disease or cancer.

Fig. 1. Carotenoids – the colourant agents of nature.

About 50 of the 600 carotenoids belong to the group of provitamins A. These carotenoids can be converted by the human body to retinol, an active form of vitamin A. As a result foods that contain carotenoids can help prevent vitamin A deficiency. Interestingly the conversion decreases when body stores of vitamin A are high. As a consequence beta carotene is a safe source of vitamin A without any toxicity effects of its teratogenic characteristics. It is discussed that positive effects of beta carotene on the immune system activity are based on its provitamin A function. Furthermore the positive effect on reproductive system function could also be based on the provitamin A property of beta carotene. The latter is well proven in animal nutrition studies.

There is a lot of epidemiological evidence as well as many supplementation studies which show that increased serum levels of lutein and zeaxanthin are associated with increased macular pigmentation. The macula is a small yellow part of the retina in the eye. It is the centre for sharp and focused vision. The yellow colour comes from the embedded lutein and zeaxanthin. As we age, levels of the pigments in the macula decrease naturally thereby increasing the risk of age-related macular degeneration (AMD). By supplementation of the two carotenoids the degeneration process can be stopped or at least slowed. Lutein and zeaxanthin are the only carotenoids capable of filtering harmful blue light. Blue light possesses the highest energy level of the visible spectrum, and this energy has the potential to cause damage to the retina and as a consequence to the photoreceptors. It is

also possible that lutein and zeaxanthin act directly to neutralise oxidants formed in the retina.
The results of several epidemiological studies state that lycopene-rich diets are associated with significant reductions in the risk of prostate cancer, particularly more aggressive forms. Lycopene is the predominant carotenoid in human plasma and is one of the most potent antioxidants. It is not yet clear if this characteristic of lycopene is related to the beneficial effects against prostate cancer.
Carotenoids are non-toxic consequently they are safe molecules for the intended use. Even in high concentrations no toxicities were reported. High doses can result in a transient discolouration of the skin. Neither mutagenic nor teratogenic effects were observed.

3. Chemical and Commercial Basics of Carotenoids

Normally carotenoids are built up by eight isoprene units and therefore contain 40 carbon atoms. All carotenoids may be formally derived from the acyclic $C_{40}H_{56}$ structure. Carotenes are pure hydrocarbons; their oxygenated derivatives are named xanthophylls. Xanthophylls have compared with carotenes slightly different electron configurations and therefore are often yellow pigments. In nature the central backbone of the molecule structure with nine conjugated carbon-carbon double bonds is always an all-*trans* isomer. The long conjugated carbon skeleton is essential for the main biological property of carotenoids, the efficient scavenger of free radicals since the required energy for a change of the electron state is very low. Also the colour spectrum of carotenoids is affected by the range of energy of light absorbed by the molecule. Cooking carotenoids may result in the formation of other isomers with a normally lower bioavailability. In canned carrots for example the all-*trans* beta carotene content is lowered by about 25% compared to fresh carrots. On the other hand lycopene from tomato products processed at high temperatures is much better absorbed than from fresh tomatoes. Chopping, homogenising and cooking disrupt the plant matrix increasing the bioavailability of carotenoids. Addition of some oil will increase the bioavailability of the fat-soluble carotenoids from natural sources.
Interestingly the bioavailability of carotenoids from supplements is much better than from natural sources. The most popular carotenoids are available as supplements of chemically synthesised products as well as of extracts from natural sources. The first synthesis of commercial quantities of beta carotene was in 1954. In the last 50 years chemists of different companies worked hard to optimise the synthesis routes as well as increase the yields of chemical reactions. Nevertheless the large-scale synthesis of carotenoids is still a challenge. Commercially the chemically synthesised products have a much higher market share. The total global food and feed carotenoids market values several hundred million Euros. DSM has a leading position in the carotenoids market and offers the following carotenoids products:

- Beta carotene for the food and feed industry
- Canthaxanthin for the food and feed industry
- Apocarotenoic ester for the food and feed industry
- Astaxanthin for the feed industry
- Zeaxanthin for the food industry
- Lutein for the food industry
- Lycopene for the food industry

In Fig. 2 the chemical formulas of these most popular carotenoids are given.

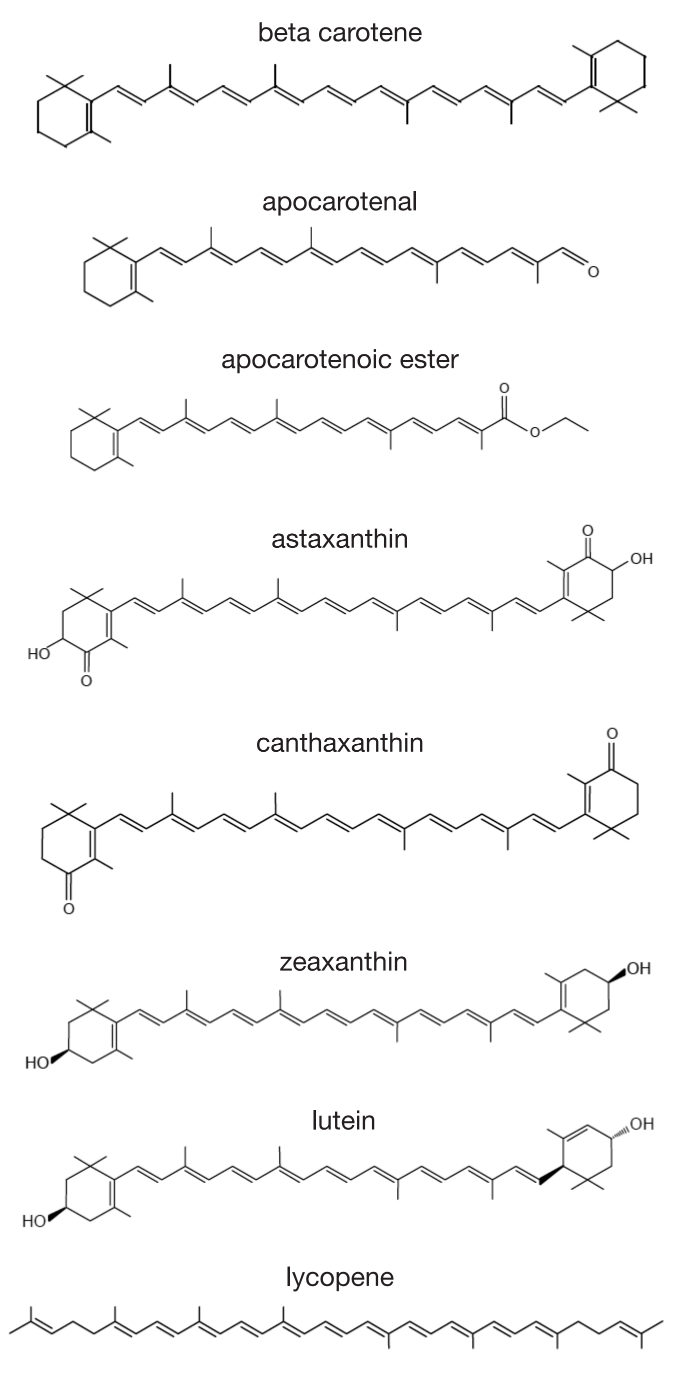

Fig. 2. Chemical formulas of commercially available carotenoids.

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