Haematococcus astaxanthin: applications for human health and nutrition

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The carotenoid pigment astaxanthin has important applications in the nutraceutical, cosmetics, food and feed industries. *Haematococcus pluvialis* is the richest source of natural astaxanthin and is now cultivated at industrial scale. Astaxanthin is a strong coloring agent and a potent antioxidant – its strong antioxidant activity points to its potential to target several health conditions. This article covers the antioxidant, UV-light protection, anti-inflammatory and other properties of astaxanthin and its possible role in many human health problems. The research reviewed supports the assumption that protecting body tissues from oxidative damage with daily ingestion of natural astaxanthin might be a practical and beneficial strategy in health management.

Astaxanthin is the main carotenoid pigment found in aquatic animals and is present in many of our favorite seafoods including salmon, trout, red seabream, shrimp, lobster and fish eggs. It is also present in birds such as flamingoes and quails. In many of the aquatic animals in which it is found, astaxanthin has several essential biological functions including protection against oxidation of essential polyunsaturated fatty acids; protection against UV light effects; immune response; pigmentation; communication; reproductive behavior and improved reproduction [1]. Some microorganisms are rich in astaxanthin – the Chlorophyte alga *Haematococcus pluvialis* is believed to accumulate the highest levels of astaxanthin in nature. Commercially grown *H. pluvialis* can accumulate >30 g of astaxanthin kg^{-1} dry biomass [2].

Astaxanthin is closely related to other well-known carotenoids, such as β-carotene, zeaxanthin and lutein, thus they share many of the metabolic and physiological functions attributed to carotenoids. The presence of the hydroxyl and keto endings (Fig. 1) on each ionone ring, explains some unique features, such as the ability to be esterified, a higher anti-oxidant activity and a more polar configuration than other carotenoids. Free astaxanthin is particularly sensitive to oxidation. In nature, it is found either conjugated to proteins, such as in salmon muscle or lobster exoskeleton, or esterified with one or two fatty acids, which stabilize the molecule. In *H. pluvialis*, the esterified form predominates, mostly as astaxanthin monoester [1]. Various astaxanthin stereoisomers are found in nature that differ in the configuration of the two hydroxyl groups on the molecule (Fig. 1). The $3S,3'S$ stereoisomer is the main form found in *H. pluvialis* and in wild salmon [3].

Astaxanthin cannot be synthesized by animals and must be acquired from the diet. Although mammals and most fish are unable to convert other dietary carotenoids into astaxanthin, crustaceans (such as shrimp and some fish species including koi carp) have a limited capacity to convert closely related dietary carotenoids into astaxanthin, although they benefit from being fed astaxanthin directly. Mammals lack the ability to synthesize astaxanthin or to convert dietary astaxanthin into vitamin A: unlike β-carotene, astaxanthin has no pro-vitamin A activity in these animals [4].

Bioavailability and pharmacokinetics

The various steps of digestion, absorption and plasma transport of dietary carotenoids in mammals have been reviewed [5]. In the plasma, non-polar carotenoids such as β-carotene, α-carotene or lycopene, are mostly transported by very low density lipoproteins (VLDLs) and low density lipoproteins (LDLs) and polar carotenoids, such as zeaxanthin or lutein, are more likely to be transported by LDLs and high density lipoproteins (HDLs). The only study on humans to date confirmed the bioavailability of astaxanthin supplied in a single high dosage of 100 mg and its transport in the plasma by lipoproteins [6].

Astaxanthin as an antioxidant

Free radicals (e.g. hydroxyl and peroxyl radicals) and highly reactive forms of oxygen (e.g. singlet oxygen) are produced in the body during normal metabolic reactions and processes. Physiological stress, air pollution, tobacco smoke, exposure to chemicals or exposure to ultraviolet (UV) light, can enhance the production of such agents. Phagocytes can also generate an excess of free radicals to aid in their defensive degradation of the invader. Free radicals can damage DNA, proteins and lipid membranes. Oxidative damage has been linked to aging, atherogenesis, ischemia-reperfusion injury, infant retinopathy, age-related macular degeneration and carcinogenesis [7].

Dietary antioxidants, such as carotenoids, might help to prevent and fight several human diseases. Carotenoids are

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