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Review

Chemical stability of astaxanthin integrated into a food matrix: Effects of food processing and methods for preservation

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ABSTRACT

Astaxanthin is a carotenoid pigment found in numerous organisms ranging from bacteria to algae, yeasts, plants, crustaceans and fish such as salmon. Technological importance of this pigment emerged from various studies demonstrating that it is a powerful antioxidant, even with higher activity than alpha-tocopherol and other carotenoids. It has been included in various pharmaceutical products because of several beneficial properties. By its nature, astaxanthin is susceptible to degradation and can undergo chemical changes during food processing. Therefore, different studies have focused on improving the stability of the carotenoid under conditions such as high temperatures, pressures and mechanical force, among others. In this review, common processes involved in food processing and their effect on the stability of astaxanthin, integrated into a food matrix are discussed. Moreover, preservation techniques such as microencapsulation, inclusion in emulsions, suspensions, liposomes, etc., that are being employed to maintain stability of the product are also reviewed.

Contents

1. Introduction

Carotenoids are tetraterpenes consisting of linked isoprene units responsible for imparting colouration to pigments (Fennema, 2000; Meléndez Martínez, Vicario, & Heredia, 2004). They are lipophilic compounds that interact with, and bind to, hydrophobic surfaces of cell membrane (Fig. 1). They are also capable of absorbing light and capturing singlet oxygen (Rodriguez-Amaya, 1999). Furthermore, xanthophylls are oxygenated functional groups modified within, in the case of astaxanthin (Fig. 2), the polyene chain, such that they are joined at each end with two β rings having a hydroxy (carotenoids – OH) functional group and one keto (CO) at each end, which confers

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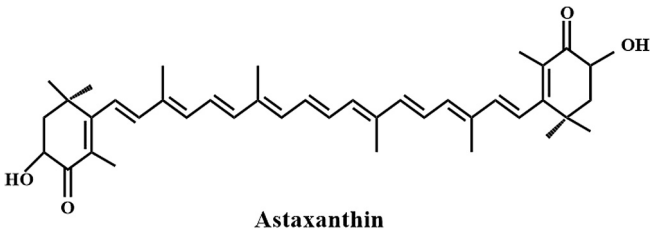

Fig. 1. The chemical structure of astaxanthin.

antioxidant properties (Rao, Phang, Ravi, & Ravishankar, 2014). Astaxanthin is red in colour. However, when the native astaxanthin complexes with proteins (carotenoproteins) or lipoproteins (carotenolipoproteins) it produces blue or purple tones, but upon denaturation the complex turns red (Fennema, 2000; Higuera-Ciapara, Felix-Valenzuela, & Goycoolea, 2006).

Astaxanthin is a metabolic byproduct of several microorganisms. The most common sources of astaxanthin are from algae *Haematococcus pluvialis*, yeast *Phaffia rhodozyma*/ *Xanthophyllomyces dendrorhous*, waste of crustaceans such as shrimp, bacteria *Bacillus circulans*, *Agrobacterium aurantiacum* and also some plants such as Adonis sp. (Cunningham & Gantt, 2011; Polívka & Frank, 2010).

There is great interest around astaxanthin due to the characteristics attributed to carotenoids, especially its biological activity as a potent antioxidant; approximately 10 times more effective than β-carotene and lutein, and approximately 100 times higher than alpha tocopherol (Higuera-Ciapara et al., 2006; Rao et al., 2014). It protects against fatty acid oxidation (Barros, Poppe, & Souza-Junior, 2011) and is involved in improving metabolism (Tejera et al., 2007). In aquaculture it is widely used to pigment the flesh of fish such as salmon or trout with a characteristic pink colour, and as a nutritional component that improves survival in juvenile stages of fish (Gouveia & Empis, 2003).

However, its use in the food industry is limited because of its highly conjugated structure and unsaturated nature. During food processing it becomes unstable and susceptible to degradation, especially when removed from its biological matrix and exposed to chemical changes induced by the conditions of the industry (Bjerkeng et al., 1997; Chen, Chen, Guo, Li, & Li, 2007; Chen, Wu, Wu, Fang, & Wu, 2007; Meléndez Martínez et al., 2004). Carotenoid degradation not only leads to loss of its functional properties, but also decreased nutritional value of food, reduced colouration and loss of organoleptic characteristics. It is important, therefore, to analyze the effects of different factors that affect the integration into a food matrix during food processing, such as high temperatures, presence of oxygen, light and pH, on the integrity of astaxanthin (Gouveia & Empis, 2003; Herrera-Andrade, Sánchez-Machado, López-Cervantes, Núñez-Gastélum, & Moreno-Ramos, 2011). The reactions that can occur in the food matrix, especially those leading to the loss of active ingredients, need process optimization for prevention of damage to the carotenoid integrity (Boon, McClements, Weiss, & Decker, 2010).

There are various methods that have been developed for improving the preservation of astaxanthin in food, including microencapsulation comprising emulsions, liposomes, and polymeric nanospheres with β-cyclodextrin complexes or calcium ions (Rao et al., 2014; Raposo, Morais, & Morais, 2012; Tachaprutinun, Udomsup, Luadthong, & Wanichwecharungruang, 2009).

2. Chemical structure of astaxanthin

Carotenoids are characterized by a system of conjugated double bonds with electrons pi (π) offshore (Boon et al., 2010). Astaxanthin is a carotenoid with the chemical name 3,3′-dihydroxy-4,4′-diketo-β-β carotene (Herrera-Andrade et al., 2011) that has the molecular formula $C_{40}H_{52}O_4$ with a molar mass of 594.84 g, and presents two asymmetric carbons located at the 3′ and 3′ β-ionone ring (Rao et al., 2014). The double bonds of the polyene chain can exist in the *cis* or *trans* configurations, also designated as E/Z conformations (Rodriguez-Amaya, 2001) (Fig. 3). Its orientation is responsible for the shape and length of the molecule (Boon et al., 2010). Most carotenoids found in nature are predominantly *trans* isomers that are usually thermodynamically more stable than the *cis* (Chen, Wu, et al., 2007, Chen, Chen, et al., 2007; Higuera-Ciapara et al., 2006).

Astaxanthin can be found as esterified or non-esterified, on one or both hydroxyl groups with various fatty acids such as palmitic, stearic or linoleic acids (Higuera-Ciapara et al., 2006). The unesterified form is more susceptible to oxidative degradation (Niamnuy, Devahastin, Soponronnarit, & Raghavan, 2008). It can present as geometrical isomers and three optical isomers (Rao et al., 2014). The three configurational isomers that may result from the different ways in which the hydroxy groups are attached to the

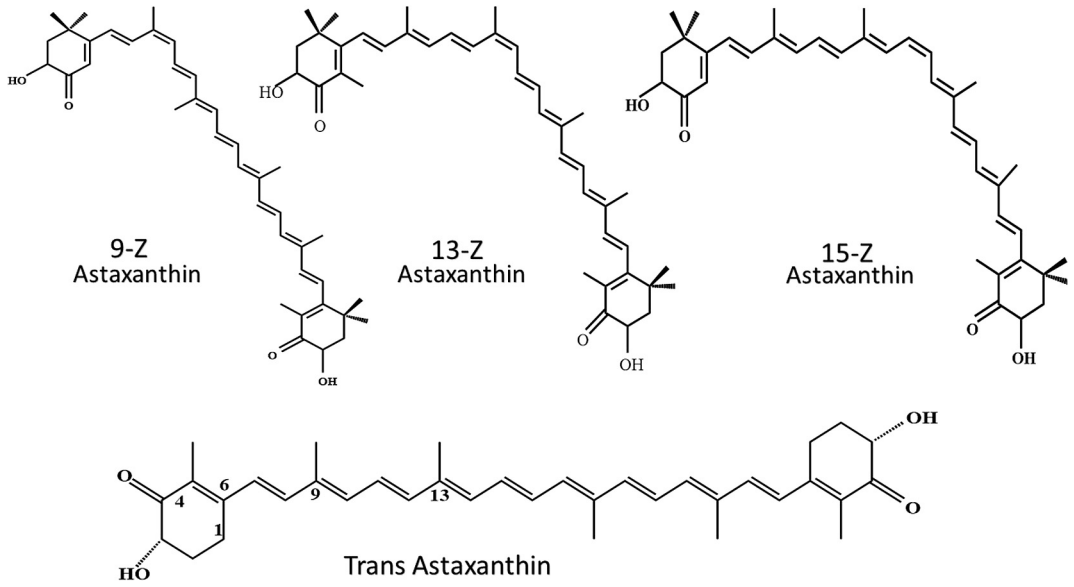

Fig. 2. Cis and trans isomers of astaxanthin.