Stability application and research of astaxanthin integrated into food

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Abstract. Astaxanthin is a kind of keto carotenoid which is with higher activity compare to alpha-tocopherol and other carotenoids. Due to its strong antioxidant capacity and various special functional properties, it has been widely used in the food. Besides, it has high value in nutrition. During food processing, Astaxanthin would be unstable, easily degraded, and the chemical reaction would be easy to occur. This paper discussed the effects of the common processes in food processing on the stability of astaxanthin, and the preservation techniques that integrated astaxanthin into food matrices to maintain its stability, such as microencapsulation, contained in liposomes, emulsions, suspensions, etc.

1. Introduction
Astaxanthin has the chemical name 3, 3-dihydroxy-β,β-carotene-4,4-dione, and its molecular formula is C₄₀H₅₂O₄ [1]. It is considered to be the strongest anti-oxidation capacity found so far. It is widely found in organisms such as shrimp, crabs, microalgae, and bird feathers. It is a terpene unsaturated compound that is fat-soluble, insoluble in water, and easily soluble in organic solvents. Astaxanthin is usually bright red or orange, producing blue or purple shades when natural astaxanthin is combined with proteins or lipoproteins, but turns red when denatured [2]. Astaxanthin is mainly present in free and esterified forms. The free astaxanthin is extremely unstable and easily oxidized. Usually chemically synthesized astaxanthin is in its free form. Esterified astaxanthin is stable due to the presence of a hydroxyl group in the terminal cyclic structure, which tends to form esters with fatty acids. The natural astaxanthin is mainly esterified.

2. Function and application of food astaxanthin
Astaxanthin has great health benefits for humans as a food additive. In addition to known anti-inflammatory effects, enhanced immunity, prevention of cardiovascular and cerebrovascular diseases and other functions. Recent studies have shown that astaxanthin also has the functions of preventing photoaging, repairing skin [3,4], protecting vocal cords [5], reducing obesity [6], preventing depression [7,8], improving sleep [9], etc. It has certain inhibitory effects on human esophageal cancer [10], colon cancer [11], prostate cancer [12] and other cancers, and can also inhibit human renal fibrosis [13], hepatic fibrosis [14], osteofibrosis, and bone Cell loss [15,16] and increased sperm motility to increase the chance of pregnancy [17].
In the food industry, astaxanthin can be used not only as a functional ingredient in anti-aging, cosmetology, immune enhancement, eye-protective functional foods and health products, but also as a food coloring agent, antioxidant to effectively preserve freshness, color, taste, quality and other effects. It was used to maintain the original nutrients of foods from damage or to improve sensory traits and enhance the appeal of foods to consumers. In the European Union, astaxanthin has been approved as a new food resource (EC No.258/97) and has been approved as a raw material for dietary supplements [18]. Since 1997, the EU countries have used astaxanthin in five kind of foods. Cyanotech Corporation of America produced Bio Astin astaxanthin soft capsules and Igene Bio Group produced a series of astaxanthin products. Japan has used astaxanthin red oil for pickling of vegetables, seaweeds and fruits and has applied for a patent [19]. In China, Haematococcus pluvialis was approved as a new food resource (No. 17 Announcement 2010) by the National Food and Drug Administration in the review of new resources in 2010. The daily recommended intake dry weight is ≤ 0.8 g, but the scope of use does not include baby food.

3. The effect of food processing on the stability of astaxanthin

3.1. High temperature cooking
Thermal degradation is a common phenomenon in astaxanthin, especially heat treatment in the presence of oxygen leads to the degradation and structural isomerization of astaxanthin [20]. Studies have found that at 4 °C, 69% of astaxanthin required about 120 h to degrade, while at 25 °C and 50 °C, it completely degraded within 80 h and 32 h, respectively [21]. At the same time microwave cooking was more damaging to astaxanthin than boiling [22].

3.2. Freeze-drying
Freeze-drying is widely used in food preservation, however it may affect the stability of astaxanthin. Because lyophilized samples have a porous surface, they increase the area exposed to oxygen during storage [23]. Studies have shown that carotene in plants was dried at different storage temperatures and the dried pigments are more stable than those without drying [24], while the pigments in carotene powders have higher stability [25].

3.3. Acids and alkalis
Other food additives may also affect the stability of astaxanthin during food processing, such as acids and bases. Acids and bases can cause isomerization and esterification of astaxanthin structural double bonds. Exposure of carotenoids to different acidic media can generate ion pairs [20], were very unstable in alkaline media, and were more stable at pH 4.

3.4. Extrusion and granulation
Extrusion and granulation are widely used in food processing. It has been found that astaxanthin in fishmeal food formulas was very stable in the extrusion process and the retained value after extrusion was between 86% and 94% [26]. At the same time, in the Haematococcus biomass stored at 4 °C, carotenoids were also relatively stable after processing in a steamless granulator [27]. [28] have demonstrated that granulation processing (using a granulator that did not use steam) did not affect the carotenoid content in formulas stored at 4 °C.

4. Prevention of degradation of astaxanthin
The instability of astaxanthin makes it susceptible to degradation by environmental factors. Degradation of astaxanthin added to the food matrix can be achieved through the addition of antioxidants or the selection of more saturated fat sources that are relatively unlikely to be oxidized to prevent [20,28], such as alpha-tocopherol and ascorbic acid [29], or to resist oxidation by interacting with other food ingredients [30].
5. Astaxanthin preservation and storage techniques

Appropriate preservation techniques can reduce astaxanthin degradation, such as microencapsulation, inclusion in chitosan matrices, liposomes, emulsions or suspensions, and complexes with cyclodextrin or calcium ions [31,32]. The microencapsulation process forms a layer around the biomaterial by forming a polymer matrix or a copolymer matrix to prevent environmental influences. [33] found that lipid extracts that used glycite and gelatin to form a coacervate and wrapped shrimp waste result in improved astaxanthin stability, good dispersion in pure yogurt, and higher chroma at comparable concentrations. DNA/chitosan co-assembly was used as a nanocarrier for efficient encapsulation and delivery of astaxanthin that can be absorbed by endocytosis of intestinal epithelial cells and was a good candidate for the effective delivery and absorption of astaxanthin [34]. [35] Encapsulated astaxanthin-enriched oils in alginate and low-methoxy pectin via Ca2+-mediated vibrating nozzle extrusion techniques. After 52 weeks, the total astaxanthin retention rate was about 94%. The effect was significant. [36] used direct microchannel emulsification (MCE) to encapsulate different extracts of astaxanthin in oil-in-water (O/W) emulsion droplets. The emulsion droplets were stable at 25 °C and encapsulated within 15 days of storage and the encapsulation rate exceeded 98%. The stability of carotenoids in oil was attributed to the presence of flavonoids, polyphenols, tocopherols and vitamin E compounds. It has also been found that the addition of astaxanthin to colloidal systems or lipid solid particles helped to increase the bioavailability of the compounds [37].

After astaxanthin was stored using optimal preservation techniques, storage conditions also affected its stability [38]. Light, oxygen, and ozone may accelerate the degradation of astaxanthin. Vacuum packaging has proven to be a very effective storage method for maintaining stability and retarding the degradation rate of astaxanthin. [27] found that vacuum packaging in nitrogen was the best storage condition for both extracts of astaxanthin and biomass, and the loss of biomass in the first 2.5 months was only 2%. Refrigeration leads to optimal storage conditions and can maintain the stability of astaxanthin.

6. Summary and outlook

A large number of studies at home and abroad have demonstrated that astaxanthin has special health benefits in the human body [39], making astaxanthin already included in many food matrices to provide health benefits. However, due to the structural instability of astaxanthin and its inability into maintain its integrity after food processing, care must be taken to maintain its stability during processing and storage. That astaxanthin functioned as a functional factor in foods. This article described in part the treatment conditions for each of the substrates studied, which showed that each parameter should be maximized to preserve astaxanthin, but this still required further study optimization.

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