

Natural vs. synthetic astaxanthin: properties, applications and market perspectives

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Abstract

Astaxanthin (ATX), a red amphiphilic keto-carotenoid, has attracted significant attention in the food and cosmetic industries due to its potent antioxidant properties, being 10 to 1000 times more effective than other natural antioxidants, and offering a wide range of health benefits, including cardioprotective, hepatoprotective, neuroprotective, anti-inflammatory, anticancer and skin-rejuvenating effects. Natural ATX is produced by the microalga *Haematococcus pluvialis* and accumulates in organisms such as shrimp and salmon that feed on it. At the industrial scale ATX can also be derived from the yeast *Xanthophyllomyces dendrorhous* (formerly *Phaffia rhodozyma*). The European Union (EU) approved ATX-rich oleoresin from *H. pluvialis* as novel food. Other novel dietary sources of ATX include oils from crustacean *Calanus finmarchicus* and Antarctic krill. Although natural ATX offers various benefits, it faces challenges such as low stability, variability in pigment composition, and, most importantly, a high price. Consequently, a significant portion, about 40%, of the ATX available on the market is synthetic. However, synthetic ATX exhibits weaker antioxidant activity compared to its natural counterpart due to the absence of accompanying bioactive compounds and its differing isomer composition. According to EU regulation 2020/998, synthetically obtained astaxanthin-dimethyldisuccinate is approved as a feed additive for fish and crustaceans. The European Food Safety Authority has set the acceptable daily intake for both natural and synthetic ATX at 0.2 mg/kg body weight. ATX is gaining broader application as new biological properties are discovered, driving market growth.

Keywords

Astaxanthin, antioxidant, dietary supplement, *Haematococcus pluvialis*, food regulation.

1. Introduction

Carotenoids are polyene pigments that support photosynthesis and protect plants from reactive oxygen species (ROS). As a result, their consumption also contributes to photoprotection and cellular defense against free radicals in animals and humans. Additionally, carotenoids containing a β -ionone ring serve as precursors of vitamin A (Stahl, Sies, 2003). Natural carotenoids are typically obtained through extraction from plants or algae. Despite their numerous health benefits, they exhibit some limitations, including low stability, the presence of undesirable accompanying substances, variability in pigment composition and complicate color standardization. Due to the high market demand for carotenoids, including vitamin A, chemical synthesis remains the primary method of production. Among nearly 700 naturally occurring carotenoids, only a few: lycopene, canthaxanthin, astaxanthin (ATX), β , β -carotene, β -apo-8'-carotenal, β -apo-8'-carotene and citranaxanthin, are currently synthesized on an industrial scale (Bogacz-Radomska, Harasym, 2018). Among them, ATX ($C_{40}H_{52}O_4$, 3,3'-dihydroxy- β , β -carotene-4,4'-dione) has attracted particular attention in the scientific community due to its unique chemical structure and its wide range of potential applications in nutraceuticals, cosmetics and pharmaceuticals. It is worth mentioning that, the number of annual publications on ATX increased from 31 in 2000 to 460 in 2024. To date, over 4,100 scientific papers on ATX have been indexed in the PubMed database (Figure 1).

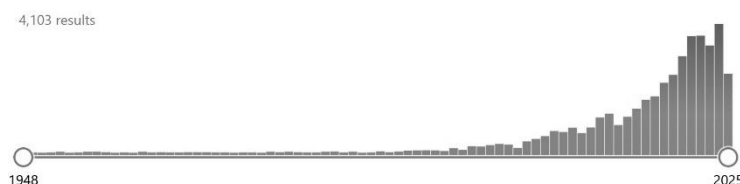


Figure 1. Increase in the number of scientific publications on astaxanthin indexed annually in PubMed, from just a few papers in the mid-20th century to over 400 per year by 2024

Source: PubMed.

This rising interest in ATX is mainly due to its broad biological activity, including cardioprotective, hepatoprotective, immunomodulatory, anti-inflammatory, neuroprotective, anticancer, vision-enhancing and skin-rejuvenating effects. Most of the health-promoting effects of natural ATX are attributed to its strong antioxidant capacity (Bjørklund et al., 2022; Ren et al., 2025). According to Lim et al. (2002) studies, its antioxidant activity is up to 54 times higher than β -carotene, 65 times higher than vitamin C and 500 times greater than vitamin E or coenzyme Q10. In the study conducted by Nishida, Yamashita and Miki (2007), it was demonstrated that the ability of ATX to quench singlet oxygen ($^1\text{O}_2$) is approximately 75 times greater than that of alpha-lipoic acid, 55 times greater than green tea catechins, 800 times greater than coenzyme Q10, and as much as 6000 times greater than vitamin C. Other studies have also highlighted ATX as one of the most powerful naturally occurring antioxidants, often referred to as the ‘king of antioxidants’ (Singh, Somagond, Deshpande, 2021). However, it is important to note that reported comparative values vary considerably across different publications. This variability arises because there is no single, universal mechanism of antioxidant action; instead, antioxidant efficacy depends on numerous factors, including the type of reactive species involved, the biological system tested, and the methodology applied. As a result, direct comparisons across studies must be interpreted with caution (Santos-Sánchez et al., 2019). This is particularly important in the case of ATX, as its various isomeric forms and esterification state directly influence its antioxidant capacity, bioavailability and potential applications (Capelli, Bagchi, Cysewski, 2013).

2. Astaxanthin sources and structure

ATX is naturally produced by some microalgae (e.g. *Haematococcus pluvialis* synonym *Haematococcus lacustris*), some yeasts (*Xanthophyllomyces dendrorhous* formerly *Phaffia rhodozyma*), and some bacteria (*Paracoccus carotinifaciens*) (Zhou et al., 2024; Nair et al., 2023). In *H. pluvialis*, ATX accumulates mainly in cytosolic lipid bodies (resting cysts) under stress conditions like high light intensity, nutrient deficiency and high salinity. ATX helps protect the cysts from the damage caused by ROS generated by these stresses. *H. pluvialis* can accumulate ATX in concentrations of up to 5% of its weight on a dry basis. By consuming ATX-rich algae, aquatic animals such as crustaceans (e.g., lobster, crab, shrimp), fish (e.g. salmon) and krill absorb the pigment which influences their color (Ren et al., 2025). Flamingos, which consume algae and crustaceans, also acquire ATX through their diet, resulting in their vibrant pink plumage (Zhou et al. 2024). The concentration of ATX varies significantly among natural sources, ranging from approximately 120 ppm in krill and 1,200 ppm in Arctic shrimp, to 10,000 ppm in the yeast *X. dendrorhous*, and reaching up to 40,000 ppm in the microalga *H. pluvialis* (Capelli, 2018:16). ATX has also been found to be naturally synthesized by certain land plants, such as *Adonis annua* and *Adonis aestivalis*: Egger, Kleinig) (Nair et al., 2023), in which it can constitute up to 1% of the dry weight of the flower petals (Cunningham, Gantt, 2005). Typical dietary sources of ATX in the human diet include seafood such shrimp, crab, lobster, salmon and rainbow trout. ATX concentrations differ markedly among aquatic species and tissue types. For instance, the concentration in European trout muscle is approximately 6 mg/kg, whereas in Japanese trout it reaches 25 mg/kg. In farmed Atlantic salmon, ATX levels range from 6 to 8 mg/kg (Ambati et al., 2014).

ATX is poorly soluble in aqueous media but it has good solubility in nonpolar solvents such as dichloromethane (~30 g/L), chloroform (~10 g/L), dimethyl sulfoxide (~0.5 g/L) and acetone (~0.2 g/L). Structurally, ATX closely resembles other carotenoids like β -carotene, zeaxanthin and lutein. Its absorption spectrum, indicative of a conjugated polyene system, shows λ_{max} values of 489 nm in chloroform, 478 nm in ethanol and 480 nm in acetone (Patil, Kasabe, Dandge, 2022).

ATX exists in three stereoisomeric forms, including two enantiomers: (3R,3'R) and (3S,3'S), and a meso form (3R,3'S) (Figure 2). It also occurs in various geometric isomers, with all-trans-ATX being the most predominant. In nature, as well as in chemically synthesized ATX, at least two cis isomers are present. Natural ATX predominantly occurs in a form esterified with fatty acids, either as a monoester or diester (Figure 2). Esterification enhances its affinity for cell membranes and improves its stability. Its red-orange color results from the presence of thirteen conjugated double bonds (Stachowiak, Szulc, 2021). The long hydrophobic chain, combined with two hydroxyl groups and two carbonyl groups, gives ATX an amphiphilic character which enables its strong affinity for cell membranes and facilitates its penetration through them (Figure 3). This property allows ATX to protect cells from oxidative stress more effectively than β -carotene or lutein (Patil, Kasabe, Dandge, 2022). ATX is a fat-soluble compound and is believed to have increased absorption when consumed with dietary fats or oils (Ambati et al., 2014).

3. Chronology of astaxanthin authorization and safety assessments

In 1937, Richard Kuhn isolated and identified ATX from lobster (Kuhn, Soerensen, 1938). The name 'asta' originates from 'Astacus' which is the scientific genus name for lobsters. In the 1970s, Hata, Katayama and colleagues investigated the biosynthetic pathway of ATX in colored varieties of goldfish, nishikigoi, and Japanese tiger prawn, examining the metabolism of dietary carotenoids like zeaxanthin and β -carotene. Additionally, Kitahara, Hata and co-researchers contributed to understanding ATX metabolism in salmon (Nishida et al., 2023).

In the 1980s, the U.S. Food and Drug Administration (FDA) began evaluating ATX as a feed additive intended to color the flesh of farmed fish. In 1995 FDA officially approved ATX as a color additive in feed for salmonids, allowing farmed fish to develop the characteristic pinkish-red flesh color (U.S. Government, 1995). Also, in 1995 Sweden has authorized the use of ATX in food supplements at a maximum daily intake of 8 mg. In 2010, the FDA issued a no-objection response to GRAS Notice No. GRN 000294, supporting the conclusion that *H. pluvialis* extract containing ATX esters is generally recognized as safe (GRAS) for use as a food ingredient (FDA, 2010).

In 2014, the European Commission, the Panel on Nutrition, Novel Foods and Food Allergens (NDA) assessed the safety of the novel ATX-rich ingredient derived from microalgae *H. pluvialis*, and an acceptable daily intake (ADI) of 0.034 mg/kg body weight was established (EFSA NDA Panel, 2020). In 2017, ATX-rich oleoresin from *H. pluvialis* algae was added to the European Union's Novel Food list for use in dietary supplements (Commission Implementing Regulation (EU), 2017/2470). It is worth mentioning here that novel food refers to food that was not significantly consumed in the EU before 15 May 1997 (Regulation (EU), 2015/2283).

According to Commission Implementing Regulation (EU) 2024/1026 of 8 April 2024, amending Implementing Regulation (EU) 2017/2470 regarding the specifications of the novel food 'astaxanthin-rich oleoresin from *H. pluvialis*' ATX is diluted and standardized to 2.5%, 5%, 7%, 10%, 15% or 20% using specific oils (Commission Implementing Regulation (EU), 2024). Currently, ATX from *H. pluvialis* is permitted in food supplements at levels of up to 8 mg per day for adults and adolescents aged 14 years and older, up to 5.7 mg per day (equivalent to 57 mg of the oleoresin) for adolescents aged 10 to under 14 and up to 2.3 mg per day (23 mg of the oleoresin) for children aged 3 to under 10. It should be noted that, other EU-approved dietary sources of ATX include oils derived from the crustacean *Calanus finmarchicus* which contains ATX esters and Antarctic krill from *Euphausia superba* (Commission Implementing Regulation (EU), 2017/2470). It is also worth mentioning that EFSA has established an ADI for ATX at 0.2 mg/kg body weight which applies to ATX derived from both *H. pluvialis* and synthetic (EFSA NDA Panel, 2023).

Since 2020, synthetic water-soluble ATX (AstaSana 5% CWS/S-TG by DSM Nutritional Products LLC) has been approved in the USA as a dietary supplement, with a safe limit set at 12 mg ATX per kilogram of body weight per day (equivalent to 240 mg AstaSana per kilogram of body weight) (FDA, 2025). Nevertheless, in the EU, only natural ATX is permitted for use in the pharmaceutical, cosmetic and food industries. Currently, there is an ongoing campaign promoting synthetic ATX, highlighting its numerous advantages over natural sources (Cardax Inc., 2023).

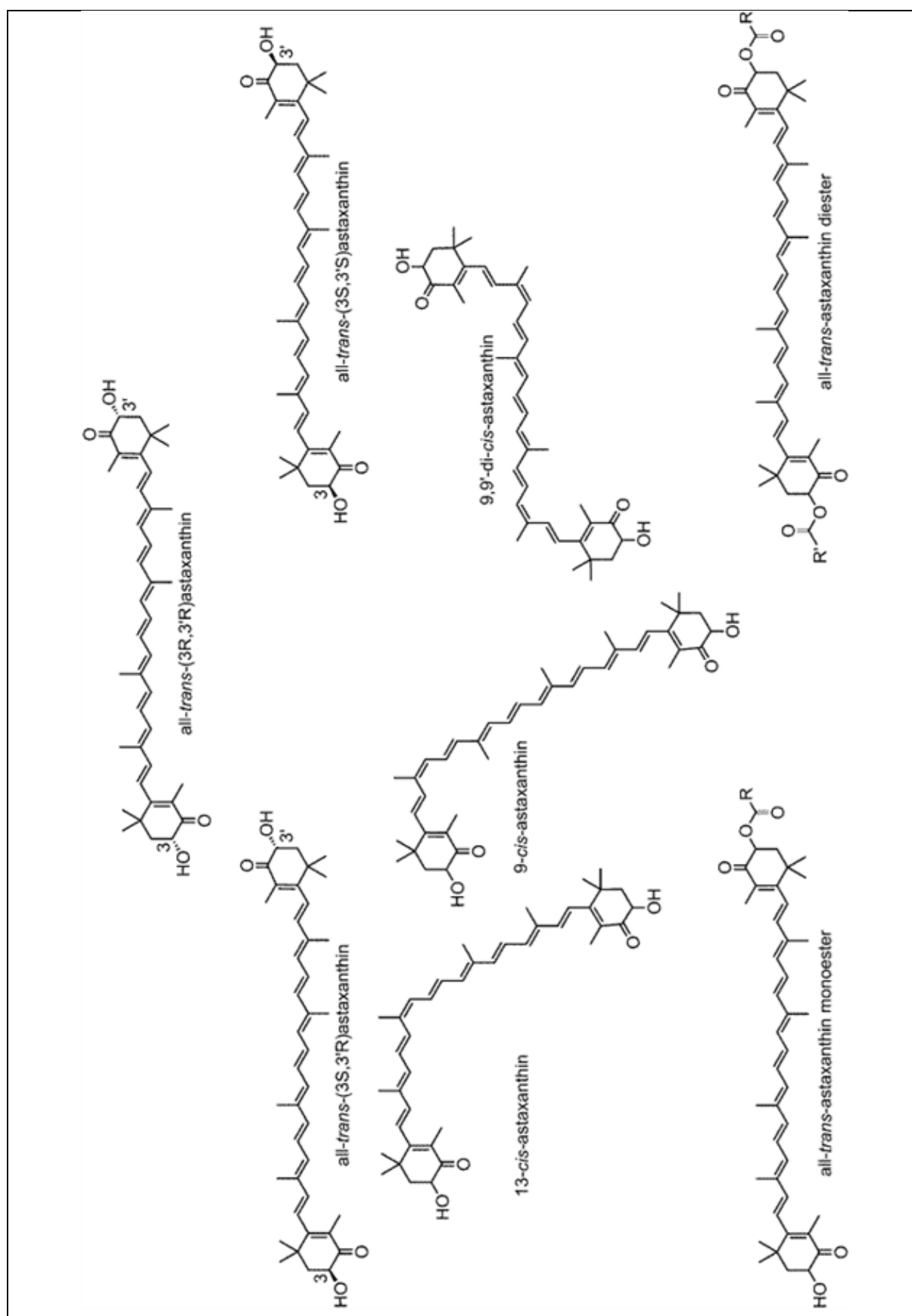


Figure 2. Chemical structure of free and esterified astaxanthin
Source: (Subramanian, 2015).

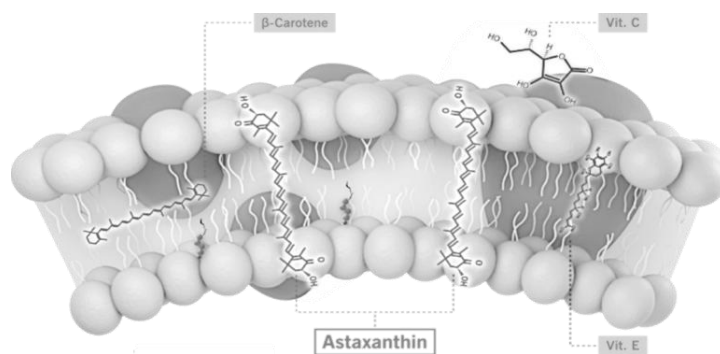


Figure 3. Distribution and orientation of astaxanthin, β -carotene, vitamin C and vitamin E in the lipid bilayer
Source: (Patil, Kasabe, Dandge, 2022).

4. Synthetic astaxanthin

Synthetic ATX is typically produced from petrochemicals, using a multi-step chemical process. Numerous methods have been developed for ATX synthesis, with the oldest and most commonly used being the Wittig reaction involving two C15-phosphonium salts and a C10-dialdehyde. Other approaches include hydroxylation of canthaxanthin, a C10 + C20 + C10 synthesis through dienolether condensation and the isomerization of lutein extracted from marigold to zeaxanthin, followed by oxidation to ATX (Figure 4) (Nguyen, 2013).

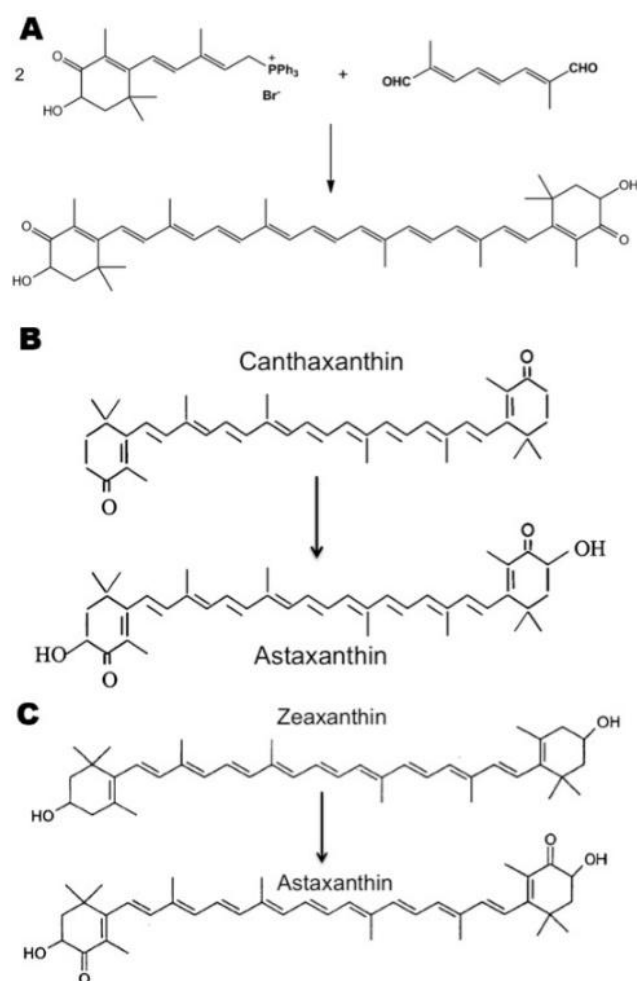


Figure 4. Astaxanthin-producing reactions: (A) Wittig reaction, (B) hydroxylation of canthaxanthin, (C) oxidation of zeaxanthin
Source: (Nguyen, 2013).

Chemical synthesis of ATX is currently the most cost-effective production method which is why synthetic formulations account for over 95% of the feed market. For comparison, the production cost of 1 kg of synthetic ATX is estimated at approximately \$1,000, while its market value exceeds \$2,000. In contrast, 1 kg of ATX derived from the yeast *X. dendrorhous* costs around \$2,500, and ATX from the microalga *H. pluvialis* costs approximately \$7,000 per kg (Nishida et al., 2023; Lim et al., 2002). Synthetic ATX formulations are water-dispersible even in cold water and exhibit greater stability compared to natural ATX, along with superior purity. From an environmental perspective, synthetic ATX production emits less CO₂ and requires fewer energy, resources, and land compared to microalgal cultivation methods (Cardax Inc., 2025).

Unfortunately, synthetic ATX has lower antioxidant activity (ca. 20–50 times) specifically, reduced efficiency in neutralizing reactive oxygen species compared to natural ATX. This is due, in part, to the absence of accompanying bioactive compounds and the differences in stereoisomer composition (Adigüzel, Ülger, 2024). Synthetic ATX typically comprises a mixture of the stereoisomers (3R,3'R), (3R,3'S) and (3S,3'S) in a 1:2:1 ratio (Stachowiak, Szulc, 2021). In turn, in wild salmon muscle, the predominant isomer is (3S,3'S) (70–85%), while the (3R,3'R) and meso forms account for 12–28.2% and 2–6%, respectively (Nishida et al., 2023; Lim et al., 2002). In contrast, ATX from *H. pluvialis* consists of 87.6% (3S,3'S), 10.1% meso, and 2.3% (3R,3'R). ATX derived from *P. rhodozyma* contains 98.5% of the (3R,3'R) enantiomer and 1.5% meso form (Moretti et al., 2006). It is worth noting that nearly all human studies demonstrating beneficial health effects of ATX have used the (3S,3'S) stereoisomer. Although data on the bioavailability and distribution of all ATX isomers in humans remain limited, available in vitro and in vivo studies suggest that the 13-cis ATX isomer, rather than the 9-cis form, is preferentially absorbed, indicating higher bioavailability. It is likely formed via isomerization of all-trans ATX. The toxicity of individual ATX isomers has not been studied separately (EFSA NDA Panel, 2023).

ATX-dimethyldisuccinate (ATX-DMDS) is approved in the EU as a feed additive for fish and crustaceans (Commission Implementing Regulation (EU), 2020/998). This compound has no harmful effects on animal health, consumer safety or the environment. In the intestines of fish, ATX-DMDS is hydrolyzed and converted into free ATX which is subsequently absorbed, metabolized and distributed to tissues. ATX-DMDS is sensitive to oxidation, light and temperature, therefore, it requires stabilization with antioxidants and, if necessary, additional embedding in a polysaccharide and/or gel matrix (Nishida et al. 2023; EFSA NDA Panel 2023; Commission Implementing Regulation (EU) 2020/998). Since 2013, free (i.e., non-esterified) synthetic ATX which is identical to natural ATX but differs in isomer ratio as mentioned earlier, has been available on the market. According to the manufacturer DSM Nutritional Products LLC, under U.S. food regulations, this form of ATX does not require authorization by the FDA (Grebrow, 2016). Nevertheless, in 2020, the company submitted a notification to introduce synthetically produced crystalline ATX, marketed as AstaSana 5% CWS/S-TG as a new dietary ingredient in the U.S. (notification number 1173) (FDA, 2025). The main current players in the synthetic ATX market are listed in Table 1.

Table 1. Key players in the synthetic ATX market

Company name	Country	Brand name
BASF SE	Germany	Lucantin Pink
DSM- Firmenich	Netherlands	AstaSana (up to 2023), Carophyll Pink
Cardax, Inc.	USA (Hawaii)	e.g. CDX-085
Zhejiang NHU Co., Ltd.	China	Not branded

Source: Authors' own work.

Recent studies on black tiger prawn (*Penaeus monodon*) have shown that synthetic ATX significantly improves growth performance, feed efficiency and pigmentation compared to natural sources. It also enhances the n-3 polyunsaturated fatty acids content in muscle and supports antioxidant capacity by reducing stress-related enzyme activity. These results highlight synthetic ATX as a more

effective and economically viable feed additive for sustainable shrimp aquaculture (Huang et al., 2023). In a comparative study on rainbow trout (*Oncorhynchus mykiss*), both synthetic and natural ATX sources were evaluated for their effects on fish growth, pigmentation, antioxidant activity and immune response. Synthetic ATX (Lucantin Pink CWD, Carophyll Pink, and Essention Pink) showed superior performance in key production traits: Lucantin provided the most stable and intense pigmentation, Essention promoted the highest growth rates and Carophyll enhanced muscle quality through increased umami amino acid content. Although natural sources like *H. pluvialis* and *P. rhodozyma* improved antioxidant capacity and immunity, the synthetic forms proved more effective in optimizing growth and product quality, reinforcing their value in intensive aquaculture systems (Zhao et al., 2022).

5. Astaxanthin commercial applications

So far ATX, due to its potent antioxidant properties and vivid pigmentation, is applied across several industries, including human nutrition, cosmetics and aquaculture. Natural ATX, primarily derived from the microalga *H. pluvialis*, is valued for its high antioxidant capacity and safety profile. It is widely used in dietary supplements, sold under multiple brand labels. The main current players in the natural ATX market, along with their leading commercial brands, are presented in Table 2. Numerous health-related claims regarding ATX can be found across the websites of its manufacturers, distributors and supplement vendors.

Table 2. The main current players in the natural ATX market

Company name	Country	Brand name
Cyanotech	USA (Hawaii)	BioAstin
AstaReal/Fuji Chemical	USA/Japan/Sweden	AstaReal
Algatech (Solabia)	Israel	AstaPure
Beijing Gingko Group	China	AstaZine
Yunnan Alphy Biotech	China	AstAlphy
Divis	India/USA/Europe	AsraBead
Algalif	Iceland	Astalif
Supreme Biotechnologies	New Zealand	AstaSupreme

Source: Authors' own work.

These claims often attribute benefits such as enhanced skin health, visual function, cognitive performance and immune modulation, largely due to its capacity to scavenge reactive oxygen species and exert anti-inflammatory effects. It should be noted that all health claims related to ATX, submitted by Member States or directly by stakeholders, have been rejected by EFSA. The authority has not substantiated claims concerning skin protection from UV-induced damage, defense against *Helicobacter pylori*, contribution to normal spermatogenesis or muscle function and support for a healthy immune system (EFSA Panel NDA, 2011). In addition, after a thorough evaluation of the available evidence, the Panel concluded that no causal relationship has been established between ATX intake and the maintenance of healthy joints, tendons or connective tissues. Additionally, there is a lack of consistent, high-quality evidence demonstrating a clear cause-and-effect relationship to support claims regarding the protection of DNA, proteins or lipids from oxidative damage, the maintenance of normal vision, the regulation of blood cholesterol or the reduction of plasma C-reactive protein (CRP) levels. Consequently, these health claims remain unproven based on current data (EFSA Panel NDA, 2009).

ATX is also used in cosmetics, particularly in anti-aging formulations, where contributes to skin elasticity, UV protection and the reduction of fine lines and oxidative damage. Several skincare brands now offer ATX-enriched formulations based on algae-derived sources. Examples include 'Re'senza Astaxanthin Aging Care Essence' (Japan), which combines ATX with retinol and collagen to support skin revitalization and hydration; 'Nibu Naturals Astaxanthin Facial Serum' (UK), a jojoba-based serum

with natural ATX; ‘Kvitok Facial Serum Astaxanthin’ (Slovakia) which uses ATX and squalane; and ‘Berkovicz Tatra Cosmetics’ Astaxanthin & Vitamin C Brightening Serum’ (Poland), formulated to reduce discoloration and support skin tone evenness via antioxidant action.

ATX is increasingly incorporated into functional foods, such as fortified beverages (e.g. smoothie with WAH-TOR ATX) and chocolate (e.g. ValAsta milk chocolate), to deliver health benefits attributed to its strong antioxidant properties (Pogorzelska, Hamułka, Wawrzyniak, 2016; Dang, Li, Yu, 2024). Reflecting this trend, in March 2024 Nutrex-Hawaii, a subsidiary of Cyanotech, introduced a sugar-free gummy containing 12 mg of natural Hawaiian ATX per serving, targeting the growing segment of health-conscious consumers (Cyanotech, 2024).

As noted earlier in Section 4, ATX, primarily in its synthetic form, is widely used in aquaculture as a feed colorant to enhance pigmentation in salmon, trout and shrimp. Beyond improving coloration, synthetic ATX also boosts immune responses, stress tolerance, overall health and consequently, survival rates. Commercial products such as Lucantin Pink and Carophyll Pink are widely utilized. Similarly, synthetic ATX is incorporated into feeds for ornamental fish to intensify coloration, particularly red and orange hues, as seen in products like Tropical Astacolor (Tropical, 2025).

ATX is also used in pet food and veterinary products to promote oral health. For example, Ark Naturals Natural Protection+ Brushless Toothpaste for dogs, the first dental chew formulated with ATX, leverage its benefits in preventing plaque and tartar. In these applications, ATX enhances levels of secretory immunoglobulin A (IgA) in saliva which helps form a protective barrier on the teeth (Ark Naturals Company, 2025).

6. Innovative laboratory-scale applications of astaxanthin

Beyond its well-established commercial roles, ATX has garnered increasing interest in experimental and laboratory-scale applications across diverse scientific disciplines, where its potent antioxidant properties are driving research into novel formulations, delivery systems and biotechnological applications.

ATX has been successfully explored in the development of functional emulsion, where its addition has been shown to inhibit the oxidation of linoleic acid (Stachowiak et al., 2011). Given its remarkable antioxidant capacity, ATX presents a compelling candidate for integration into active packaging materials. Edible films, made by blending gelatin with different polysaccharides (carboxymethyl cellulose (CMC), gum arabic (GAR), octenyl succinic anhydride starch (OSA) and water-soluble soy polysaccharides (WSSP)), were enriched with synthetic, water-soluble AstaSana ATX at concentrations of 0%, 0.25%, 0.5% and 1% (Łupina, Kowalczyk, Kazimierczak, 2022; Łupina, Kowalczyk, Kazimierczak, 2021; Łupina et al., 2021). Its addition gave the films a vibrant red color and slightly grainy texture due to the presence of starch (carrier for ATX). Depending on the matrix used, the films showed different functional properties and release rates of ATX. For example, CMC-based films released AST fast, while OSA and WSSP-containing films released it more slowly and steadily which is presumably beneficial for prolonged antioxidant protection. Colín-Chávez et al. (2013) incorporated high purity natural ATX a component in polyethylene films. The migration of ATX into 95% ethanol at temperatures between 23 and 40 °C followed Fick’s diffusion law. The rising interest in ATX-enriched packaging (Inthamat et al., 2022; Nasution, Wahyuni, 2023) suggests its strong potential as a natural active material for extending food shelf life.

The study by Nurdianti, Rusdiana and Sopyan (2020) demonstrated the antidiabetic potential of ATX, showing that its nanoemulsion-loaded thin CMC-based film administered intraorally, effectively reduced blood glucose levels and preserved pancreatic β -cell integrity in diabetic rabbits, suggesting promising translational potential for non-invasive diabetes management in humans. In another study, ATX/alpha-tocopherol nanoemulsions demonstrated anticancer, wound-healing and antimicrobial activities, highlighting ATX’s potential as an effective component in drug delivery systems (Shanmugapriya et al., 2018). ATX has emerged as a promising nutraceutical candidate for supporting bone health by mitigating oxidative stress, promoting osteoblast activity and potentially preventing bone loss and related diseases (Davan et al., 2023). Also, ATX shows potential as a bioactive additive in tissue engineering, enhancing stem cell proliferation and viability within three-dimensional hydrogel scaffolds for regenerative medicine applications (Choi et al., 2019).

While ATX has a long-standing and well-established use as a colorant in aquaculture (fish and crustaceans), research strongly suggests it can be a beneficial feed additive for poultry and pigs as well. ATX supplementation in broiler chickens can enhance growth performance by increasing daily feed intake, improving feed conversion efficiency and reducing oxidative stress (Pertiwi, Mahendra, Kamaludeen, 2022). Moreover, supplementation with natural ATX, improved egg yolk color and prolonged yolk freshness during storage but had little to no impact on other egg quality or performance parameters (Heng et al., 2020; Zhu et al., 2021). Under intensive farming conditions, ATX helps maintain overall health and supports stress management in poultry (Hussan et al., 2023). Dietary supplementation with natural ATX improved the color stability and shelf life of pork products during retail display, despite having no effect on growth performance or lean quality (Carr et al., 2010).

7. Astaxanthin market

The global ATX market is projected to grow significantly from USD 1.69 billion in 2024 to USD 3.89 billion by 2030, expanding at a compound annual growth rate (CAGR) of 14.74% during the forecast period. This growth is driven by increasing demand across multiple industries, including aquaculture, nutraceuticals, cosmetics, pharmaceuticals and food, and beverages.

North America dominated the market in 2024, accounting for 35.27% of global revenue, fueled by strong demand for natural antioxidants and a well-established supplement industry. Europe follows closely, with growth driven by an aging population seeking preventive healthcare solutions. Meanwhile, the Asia Pacific region is expected to grow at the fastest rate, supported by advancements in microalgae cultivation and increasing aquaculture production in countries like China and Japan. By source, natural ATX held the largest revenue share (58.45%) in 2024, preferred for its higher efficacy and sustainability. Synthetic ATX remains cost-effective for large-scale aquaculture feed applications. In terms of product form, dried algae meal led the market due to its high yield and cost efficiency, while softgels are gaining traction in nutraceuticals for their convenience and bioavailability.

The aquaculture and animal feed segment was the largest application in 2024 (46.07% share), as ATX enhances seafood quality and consumer appeal. Nutraceuticals are the fastest-growing segment, driven by rising health consciousness and product innovations like AstaBead by Algalif and Divis Nutraceuticals. Key players such as Algatech Ltd, Cyanotech Corporation and Beijing Gingko Group are investing in production expansions and sustainable cultivation methods to meet growing demand. Recent developments include Algalif's new production facility in Iceland and Kuehnle AgroSystems' funding for innovative fermentation-based ATX production (Grand View Research,, 2024).

8. Summary

Despite the ongoing promotion of synthetic ATX and its advantages demonstrated in laboratory research, the EU currently permits only natural ATX for use in food industry. This regulatory stance, combined with growing consumer demand for clean-label and natural products, is expected to drive strong market growth for natural ATX. Meanwhile, innovative research is continuously uncovering new applications for ATX in biomedical, biotechnological, and environmental fields, suggesting that its potential extends well beyond traditional uses. However, the market faces challenges such as competition from other cheaper and better-known antioxidants like lutein, as well as regulatory hurdles in certain regions.

The future of the ATX market will likely depend on balancing regulatory policies, consumer preferences and scientific advancements. Emphasizing natural sources aligns well with current trends toward sustainability and transparency which could ultimately enhance trust and adoption. At the same time, ongoing innovation in synthetic production might offer complementary solutions, especially if safety and efficacy are assured. Overall, ATX stands as a promising compound with significant potential for diverse industries in the years ahead.

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