



### Background on Astaxanthin and its Properties

Carotenoids have been extensively studied for their health benefits in animals and humans. Carotenoids are red, yellow, or orange pigments that are produced in nature by plants, algae, and microorganisms.<sup>1</sup> The food we eat is abundant in many types of carotenoids, including the well-known compound beta carotene.<sup>1</sup> The lesser-known xanthophyll carotenoids are a remarkable class of their own and have been increasingly researched in recent years. Astaxanthin is a marine-derived carotenoid within the xanthophyll family.<sup>1</sup> It is the main carotenoid found in wild sockeye salmon and is responsible for the red color of salmon flesh.<sup>2</sup> Mammals are incapable of synthesizing astaxanthin in their bodies.<sup>1,2</sup> Instead, they must obtain astaxanthin in their diet by consuming microorganisms living in the marine environment.<sup>1,2</sup>

### Digestion, Absorption, and Transport

All carotenoids are fat soluble, though each specific compound differs in its unique chemical structure.<sup>2</sup> These structural differences alter their digestion, absorption, and transportation after being consumed.<sup>2</sup> The majority of xanthophyll carotenoids have lower solubility and lower bioavailability compared to other dietary lipids and fats.<sup>2,27</sup> However, the structure of astaxanthin differs from other xanthophyll carotenoids, making it the exception to this rule. Due to its polar structure, astaxanthin is more easily absorbed than other non-polar carotenoids like beta-carotene and lycopene.<sup>2,3</sup>

Several additional factors affect how astaxanthin is absorbed. Studies have shown that consuming astaxanthin with dietary fat can increase its absorption in the small intestines.<sup>2,4</sup> While more studies are needed in humans, rat studies have shown that astaxanthin is better absorbed when consumed with olive oil, compared to corn oil.<sup>5</sup> Astaxanthin bioavailability is also affected by meal timing, and has been shown to be better absorbed when taken right after a meal compared to on an empty stomach.<sup>3</sup> Furthermore, research has indicated that astaxanthin is up to 40% less bioavailable for absorption in smokers compared to non-smokers.<sup>3</sup>

### Natural Sources

Two scientists, Kuhn and Sorensen, are credited for being the first to extract and isolate astaxanthin from lobsters.<sup>6</sup> This propelled astaxanthin research into labs worldwide, illuminating its potential health benefits for animals and humans.

Astaxanthin is produced in marine environments by bacteria, microalgae, yeast and fungi.<sup>1,2</sup> The highest natural producer of astaxanthin is a green microalgae called *Haematococcus pluvialis* (*H. pluvialis*).<sup>1,2,7</sup> *H. pluvialis* can synthesize large amounts of astaxanthin in harsh environments, including extreme temperatures, during starvation, and under irradiation.<sup>1,2</sup> The concentration of astaxanthin in *H. pluvialis* is significantly higher than other natural producers like yeast and other marine microorganisms.<sup>7</sup> Because of the high concentration of astaxanthin in *H. pluvialis*, this microalgae is the primary source of astaxanthin that is available for marine animal consumption, like wild salmon, and subsequently for human consumption as well.<sup>2,3</sup>

Humans indirectly obtain astaxanthin in their diets by eating marine animals that eat astaxanthin producing microorganisms like *H. pluvialis* microalgae. These marine animals include salmon,



# BRISTOL BAY SOCKEYE SALMON

## Astaxanthin: A Review of the Literature

trout, lobster, crab, shrimp, and crustaceans.<sup>2</sup> The consumption of astaxanthin-producing microorganisms is responsible for the natural reddish pigment found in these species' flesh, skin, or exoskeleton.<sup>2</sup>

In animals, astaxanthin plays a role in many essential functions like immunity, reproduction, and communication. It also functions in key defense mechanisms such as protection against UV light and as antioxidants to protect against harmful cellular oxidation reactions.<sup>6</sup>

Similar benefits have been observed in humans as well, and will be reviewed in the following sections.

Synthetic forms of astaxanthin exist and can be produced as supplements.<sup>1</sup> However, the health promoting properties of these supplements is inferior to the natural form derived from microalgae.<sup>1, 8</sup>

### Food Sources

As previously mentioned, astaxanthin is responsible for the reddish hue observed in marine animals, including salmon, trout, shrimp, lobster, fish eggs, crab, and crustaceans.<sup>1, 2</sup> It is also added to feed provided to farm-raised salmon to artificially achieve the same coloring.<sup>9</sup>

The table below identifies wild sockeye salmon as containing the highest concentration of astaxanthin compared to other wild and farm-raised varieties.<sup>10</sup> Wild sockeye salmon contains between 26-38 milligrams (mg) of astaxanthin per kilogram (kg) of salmon weight.<sup>10</sup> This concentration is higher than the amounts studied in farmed salmon, trout, and charr.<sup>10</sup> It is also higher than other types of wild salmon and charr species (Table 1).<sup>10</sup>

Table 1: Astaxanthin content of different salmonids, extracted from European Food Safety Authority, 2005.<sup>10</sup>

Genus		Farmed	Wild	Astaxanthin mg kg <sup>-1</sup> flesh	References
<i>Oncorhynchus nerka</i>	Sockeye salmon		X	26 - 38	1, 3, 9
<i>Oncorhynchus kisutch</i>	Coho salmon		X	10 - 21	1, 3, 9
<i>Oncorhynchus keta</i>	Chum salmon		X	3 - 5	1, 3
<i>Oncorhynchus tshawytscha</i>	Chinook salmon		X	5.4	1
<i>Oncorhynchus gorbuscha</i>	Pink salmon		X	4 - 7	1, 9
<i>Oncorhynchus Masou</i>	Masu salmon		X	4.6	9
<i>Salmo salar</i>	Atlantic salmon		X	3 - 10	3, 4
<i>Salmo salar</i>	Atlantic salmon	X		1 - 9	4, 6
<i>Oncorhynchus mykiss</i> <sup>a</sup>	Rainbow trout	X		0 - 25	5
<i>Salvelinus alpinus</i>	Arctic charr	X		1-8	7, 8, 11
<i>Salvelinus alpinus</i>	Arctic charr		X	8.6	10

1) Kanemitsu and Aoe, 1958      2) Schiedt et al., 1986      3) Schiedt et al., 1981  
4) Skrede and Storebakken, 1986      5) Rønsholdt and McLean, 2001      6) Torrissen et al., 1995  
7) Synowiecki and Shahidi, 1997      8) Aas et al., 1997      9) Kitahara, 1984  
10) Scalia et al., 1989      11) Olsen and Mortensen, 1997

<sup>a</sup> including unpigmented trout



### Recommended Dose

The amounts of astaxanthin given to participants and animals in research studies can vary. For example, in a study performed on cyclists, astaxanthin was dosed at 4 mg/kg of cyclist weight.<sup>9</sup> On the other hand, many mice studies may dose astaxanthin at higher concentrations ranging from 420 mg/kg to 2,100 mg/kg of body weight, an amount which may not be easily replicated in human studies.<sup>9</sup>

Although wild sockeye salmon has a high concentration of astaxanthin, there is a lack of research using salmon as the source of astaxanthin consumed. Doses of astaxanthin in research studies often exceed the amount of astaxanthin in a portion of sockeye salmon. Therefore, it may not be possible to state the exact amount of salmon that would need to be consumed to achieve the benefits of astaxanthin. One study found that a 250 gram (g) portion of salmon provided 5 mg of astaxanthin.<sup>6</sup> This study also concluded that maximal blood concentrations were reached and then plateaued after one week of daily ingestion.<sup>6</sup>

As a dietary supplement obtained from *H. pluvialis*, studies have shown positive benefits from astaxanthin even at modest intakes of 40 mg/day or less.<sup>8</sup> A 10 mg dose of astaxanthin can stay in the bloodstream for 24 hours, and a dose of 100 mg for up to 76 hours.<sup>11</sup> Smaller doses of astaxanthin are more difficult to capture in the bloodstream due to limits of laboratory technology. However, studies have shown that doses as small as 1 mg taken daily for four weeks can increase levels of astaxanthin in the blood.<sup>11</sup>

Numerous studies have shown positive effects of astaxanthin consumption at various levels, and suggest that astaxanthin has many positive benefits when consumed even in small quantities. These studies and the associated benefits of astaxanthin will be covered in the following sections.

### Functions of Astaxanthin

Astaxanthin supplementation has been associated with a reduction in oxidative stress and inflammation.<sup>12</sup> The following sections will elaborate on the antioxidant and anti-inflammatory potential of the compound.

### Overview of Astaxanthin as an Antioxidant

Astaxanthin has a strong antioxidant capacity, which researchers have attributed to its atypical polar structure.<sup>8</sup> It can protect cell membranes from attacks by free radicals or cellular oxidation.<sup>8</sup> While cellular oxidation is a natural consequence of constant, necessary reactions within the body, an overabundance can overwhelm the body's capacity to restore equilibrium. This imbalance may result in oxidative stress. Astaxanthin scavenges unstable free radicals and reactive oxygen species that are formed from oxidative stressors like smoking, exposure to UV light, and obesity.<sup>2</sup> These stressors cause damage to cell function or cellular death if not neutralized by antioxidants like astaxanthin.<sup>2</sup>

Studies suggest that astaxanthin has higher scavenging activity for reactive oxygen species and free radicals compared to other carotenoids.<sup>2</sup> Astaxanthin has been shown to decrease breakdown of cell membranes by up to 41% and help keep cell membranes intact.<sup>13</sup> This is noteworthy as other carotenoids including zeaxanthin, lutein, beta-carotene, and lycopene were shown to increase cell membrane destruction.<sup>13</sup> Astaxanthin may have up to 65 times more effective antioxidant activity



than vitamin C and 50 times more effective antioxidant capacity than vitamin E.<sup>7</sup> Additionally, a mice study revealed that astaxanthin may enhance a cellular pathway that increases the expression of antioxidant enzymes.<sup>14</sup> Through these antioxidant and scavenging mechanisms, astaxanthin may play a role in protection against diseases involving inflammation, ulcers, cancer, neurodegeneration, diabetes, cardiovascular disease, and liver disease.<sup>2</sup>

### Overview of Astaxanthin as an Anti-inflammatory Compound

The central nervous system (CNS) is composed of the brain and spinal cord which are responsible for all of the body's activities and functions. Any form of cellular damage or disease can generate a stress response within the CNS, often characterized by neuroinflammation.<sup>1,8</sup> Chronic or prolonged neuroinflammation can eventually lead to permanent damage and neurodegeneration of the CNS. There are many diseases of concern when considering the ramifications of neuroinflammation and oxidation, including but not limited to: Alzheimer Disease, Parkinson's Disease, Huntington's Disease, and amyotrophic lateral sclerosis (ALS).<sup>1</sup> Drug therapies are lacking in both preventative measures and the treatment for these diseases.<sup>1</sup> This is why research into anti-neuroinflammatory and antioxidant compounds is essential for disease prevention and treatment.

Astaxanthin is highlighted in research concerning the aforementioned diseases because xanthophylls, including astaxanthin, have been found to be the preferred carotenoid used by the human brain.<sup>1</sup> In fact, the brain is one of astaxanthin's primary target organs once it is absorbed. The blood-brain barrier is the gateway to the brain and is highly selective in the types of molecules it allows to pass into the brain. Astaxanthin is one of the molecules that can pass through and function as an antioxidant and provide anti inflammatory protection to the CNS.<sup>1,8</sup>

While astaxanthin's ability to cross the blood-brain barrier makes it a key compound in research regarding neuroinflammatory conditions, inflammation also occurs throughout the body. Astaxanthin has been shown to reduce inflammation in an array of organ tissues resulting in improved function.<sup>4,8,12</sup> Specific health benefits of astaxanthin will be discussed in the following sections.

### Health Benefits of Astaxanthin

#### Neuroprotection

During the early stages of Alzheimer's Disease there is an increase in mitochondrial damage, caused by oxidative stress and cell apoptosis, or cell death.<sup>1</sup> Astaxanthin's neuroprotective role is not limited to its antioxidant capacity, but also its potential to reduce mitochondrial cell death. This was observed in a study that showed decreased seizure activity in astaxanthin supplemented rats.<sup>15</sup> Additionally, brain images of individuals with Alzheimer's Disease have shown a decrease in the size of the hippocampus. The hippocampus is responsible for short term memory and emotional processing.<sup>1</sup> This explains the personality changes and disruption of short term memory formation observed in individuals suffering from Alzheimer's Disease.<sup>1,8</sup>

Neurogenesis, the development of nerve tissue, and brain plasticity, the ability of the brain to change and form new connections, are two functions that tend to decrease in efficiency with age.<sup>1,15</sup> Considering the hippocampus is constantly evolving, learning, and forming new memories, neurogenesis and plasticity are likely essential functions for optimal hippocampal function.<sup>15</sup> Research has explored astaxanthin's ability to improve neurogenesis and plasticity as well as specifically diminishing hippocampal inflammation. Multiple rat studies have shown



reduced inflammation, neuronal damage, and cell apoptosis specifically in the hippocampus after astaxanthin treatment.<sup>1,15</sup> If replicated in humans, this could result in decreased cognitive deficits caused by hippocampal inflammation and damage. In a study of 10 men complaining of increased forgetfulness, they were dosed with 12 mg of astaxanthin per day for 12 weeks.<sup>16</sup> At the conclusion of the study they had improved reaction time, attention, and working memory.<sup>16</sup>

### **Immune Function**

Immune system cells, such as lymphocytes, are extremely susceptible to oxidative damage.<sup>4</sup> Astaxanthin has been shown to protect the membranes of immune cells against free radical damage, thus preserving immune function.<sup>4</sup>

A study on human subjects who were given either 2 mg/day of astaxanthin or 8 mg/day for 8 weeks revealed enhanced immune cell function compared to placebo groups.<sup>17</sup> The 2 mg/day dose was associated with significantly increased T-cell and B-cell lymphocytes, two major types of white blood cells in the immune system.<sup>17</sup> Natural killer cell cytotoxic activity is another important function of the immune system, which is the ability to target and destroy infected cells.<sup>4,17</sup> This study also showed that natural killer cell cytotoxicity and lymphocyte proliferation improved among the subjects who received 8 mg/day of astaxanthin.<sup>17</sup>

### **Metabolic Disease**

Metabolic disease is characterized by a range of traits, including hypertriglyceridemia, also known as high triglyceride levels in the blood, and low levels of high-density lipoprotein (HDL)-cholesterol.<sup>8</sup> These biomarkers are often observed in individuals at higher risk for metabolic disease, including overweight and obese people. Overweight and obese individuals also exhibit greater levels of oxidative stress compared to individuals who fall in the normal weight category.<sup>8</sup> In studies of overweight and obese male and female subjects, the consumption of 5 or 20 mg/day of astaxanthin for 3 weeks was associated with significantly reduced oxidative stress biomarkers.<sup>18</sup> Notably, the reduction in the stress markers was not different between the two doses, indicating that the benefits can be seen from supplementation of only 5 mg/day.<sup>18</sup> Males and females who had high levels of triglyceride lab values also showed improvements in their lab panels after 12 weeks of astaxanthin supplementation.<sup>19</sup> Taking 12 mg/day and 18 mg/day of astaxanthin were both associated with significantly reduced triglyceride levels.<sup>19</sup> Consumption of astaxanthin at 6 mg/day and 12 mg/day were associated with significantly increased HDL cholesterol levels.<sup>19</sup> These studies highlight the benefits of astaxanthin in alleviating some of the associated biomarkers of metabolic disease. By alleviating these indicators, astaxanthin may also decrease risk of metabolic disease.

### **Diabetes**

Possessing biomarkers for metabolic disorder is also associated with increased risk for diabetes and cardiovascular disease.<sup>19</sup> Oxidative stress and inflammation impact organ function and impair biological processes, which can lead to these chronic diseases.<sup>4,19</sup>

A hallmark characteristic of diabetes is hyperglycemia, or high blood sugars.<sup>4</sup> An important laboratory value associated with diabetes is hemoglobin A1C, a snapshot of an individual's average blood sugars from the past 3 months.<sup>20</sup> Oxidative stress in overweight or obese individuals can impair the pancreas and disrupt normal glucose metabolism.<sup>4,19</sup> This can lead to high blood sugars and irregular insulin function, which will impact lab values.<sup>4</sup> Another measure of oxidative stress is the tumor necrosis factor (TNF)-alpha protein, which increases during systemic inflammation.<sup>20</sup> In mice studies, astaxanthin consumption was associated with improved blood sugar and serum insulin levels.<sup>4</sup> These results are a sign of improved glucose metabolism.<sup>4</sup> Human volunteers at



risk for metabolic disease who were given 8 mg of astaxanthin twice a day for 3 months also had significant decreases in both HgA1C and TNF-alpha levels.<sup>20</sup> Astaxanthin may offer benefits in improving diabetes control, although more studies are needed.

### Cardiovascular Disease

Stress caused by oxidation or inflammation is also associated with cardiovascular health outcomes and may lead to conditions such as atherosclerosis, a buildup of plaque in the arteries.<sup>12</sup> This buildup may impair blood flow and can impact blood pressure.<sup>12</sup> Rats with hypertension, or high blood pressure, had decreased blood pressure following oral supplementation of astaxanthin.<sup>12</sup> The rats also showed an increase in nitric oxide and vasodilation of blood vessels, which promoted improvements in blood flow.<sup>12</sup>

Studies performed on mice and humans have also shown decreased oxidative stress and inflammation markers associated with atherosclerotic cardiovascular disease.<sup>21</sup> In adult participants who were given doses of astaxanthin ranging from 1.8 mg/day to 21.6 mg/day for 2 weeks, a reduction in low density lipoprotein (LDL) cholesterol oxidation was observed at all dose levels.<sup>12</sup> C-reactive protein (CRP) is another biomarker of inflammation, and is high during stress and inflammatory disease states.<sup>12</sup> Healthy females who consumed 2 mg/day of astaxanthin for 8 weeks had decreased CRP levels following supplementation.<sup>12</sup> These research studies highlight the potential for astaxanthin to improve cardiovascular health through various mechanisms.

### Eye Health

Oxidation can cause damage to all body parts and the eyes are no exception. Oxidative damage can lead to macular degeneration and cataracts, the two primary causes of visual impairment.<sup>22</sup> Lutein and zeaxanthin are two carotenoids that have been isolated in the human eye and shown to be in high concentration in the macula of the eye.<sup>22</sup> While astaxanthin has not been isolated in the human eye, it has been isolated in the eyes of other mammals, specifically in the retina.<sup>22</sup> In the rat study which concluded astaxanthin's anti-inflammatory effect on the hippocampus, the same rats had reduced retinal inflammation.<sup>1</sup> Another study demonstrated that astaxanthin fed rats had less photoreceptor damage when exposed to UV light.<sup>22</sup>

In human studies, astaxanthin has been shown to improve visual sharpness and acuity. Vision improvements were observed in studies dosing human subjects 4, 6, or 12 mg of astaxanthin per day.<sup>23, 24</sup> Reduced eye muscle fatigue has also been observed in astaxanthin treated groups. Staring at a computer monitor for long durations of time has been linked with blurry vision and eye strain or fatigue.<sup>23, 24</sup> One study found that after 4 weeks of receiving 5 mg/day of astaxanthin, eye muscle endurance was improved.<sup>8</sup> Another study replicated these effects with 6 mg/day and further supported astaxanthin's potential role in reducing eye muscle fatigue.<sup>8</sup> At the end of the trial, subjects noted improvements in eye strain, blurriness, and ability to see near objects.<sup>8</sup> One proposed mechanism for the reduction of eye fatigue and improved visual sharpness is the increase in retinal capillary blood flow that astaxanthin may promote.<sup>25</sup>

### Skin and Aging

Oxidative stress is a known promoter of skin damage and aging.<sup>6</sup> It also leads to inflammation of skin cells, which can cause further permanent damage.<sup>6</sup> Astaxanthin's skin protecting benefits are not simply due to its ability to eradicate free radicals that are generated from exposure to UV sunlight, but also its enhancement of the body's natural defense mechanisms through promoting the cellular signaling pathways responsible for antioxidant defense.<sup>6, 26</sup> There have been several studies investigating the effect of both supplemental and topical astaxanthin on human skin.



# BRISTOL BAY SOCKEYE SALMON

## Astaxanthin: A Review of the Literature

One study consisted of a placebo group and astaxanthin dosed groups of both 6 mg and 12 mg per day over 16 weeks.<sup>6</sup> While the astaxanthin dosed groups had no significant changes in wrinkle depth and moisture content at the end of the trial, the placebo groups, which had no astaxanthin treatment, had both worsened wrinkle depth and decreased moisture content of their skin.<sup>26</sup> A subsequent study in which female participants consumed 6 mg astaxanthin for 8 weeks saw a decrease in wrinkles and age spot size, as well as an increase in skin elasticity and overall texture.<sup>27</sup>

A multitude of other studies have supported these findings. Topical astaxanthin, derived from krill, was shown to reduce erythema by 60% in just 4 days.<sup>6</sup> When astaxanthin is combined with other active ingredients such as collagen hydrolysate, there is a synergistic effect observed.<sup>6</sup> Additionally, combining oral supplementation and topical administration of astaxanthin has augmented benefits. Treatment of both oral and topical astaxanthin has improved skin elasticity, wrinkles, age spot size, and skin texture.<sup>6</sup> One of the mechanisms responsible for these results is astaxanthin's promotion of pro-collagen type 1 and inhibition of collagen-degrading enzymes and elastin-degrading enzymes.<sup>6</sup>

### Gastrointestinal Health

*H. pylori* bacteria are associated with ulcers and inflammation in the gastrointestinal system, and may lead to stomach cancer in some cases.<sup>28</sup> Several studies have shown an association between astaxanthin consumption and reduction in *H. pylori* bacteria in the digestive tract.

In a clinical study, participants who received 40 mg of astaxanthin daily showed a reduction in acid reflux symptoms.<sup>21</sup> Among these participants, a more significant reduction was seen in those who were also affected by *H. pylori* bacteria, suggesting that there was suppression of both the bacteria and reflux.<sup>21</sup> Rats treated with astaxanthin also showed increased antimicrobial activity against *H. pylori* bacteria.<sup>28</sup> Treatment with astaxanthin was associated with lower levels of *H. pylori* bacteria colonization in the digestive tract and overall decreased inflammation.<sup>28</sup>

### Sports Performance

Positive effects of astaxanthin on athletic performance have been observed in different sports, including running, weight training, and cycling. In runners, astaxanthin has been associated with decreased muscle fatigue and significantly lower serum lactic acid concentration two minutes after running long distances.<sup>29</sup> Astaxanthin was also linked with a reduction in delayed-onset muscle soreness caused by exercise induced muscle damage among weightlifters.<sup>30</sup> Daily 4 mg intake of astaxanthin was associated with 50% improvement in number of squats with a barbell performed compared to the number of squats athletes were able to do prior to astaxanthin supplementation.<sup>31</sup> Cyclists who received astaxanthin supplementation showed improvements in their cycling times and power output compared to the individuals who didn't receive supplementation.<sup>9</sup> Riders who received astaxanthin were able to cycle at higher resistance levels, and had significantly faster cycling times than those who didn't receive astaxanthin.<sup>9</sup>

Additionally, animal studies have also associated astaxanthin with improvements in exercise capacity. Astaxanthin supplementation was linked with a reduction in exercise-induced damage in mouse skeletal muscle and heart muscles.<sup>28</sup> Astaxanthin also promoted lipid metabolism during exercise to improve endurance among the rats.<sup>28</sup> The switch from using glucose to using fatty acids as an energy source for exercise allowed for delayed exercise fatigue in the rats. By burning fat first, glycogen stores were saved for later stages of exercise and endurance was increased.<sup>28</sup>



### Fertility

There are few studies on the use of astaxanthin for fertility treatments; however existing studies show promising results in both humans and animals. One mice study focused on the effects of astaxanthin on sperm recovery. Mice were exposed to a compound used in cancer treatments, which has been linked with sperm DNA damage.<sup>32</sup> Mice who were given 25 mg/kg of astaxanthin for 5 days a week for 5 weeks total showed improvements in sperm count, testes weight, and sperm head morphology, compared to mice who did not receive astaxanthin<sup>32</sup> While this study has not been replicated in humans yet, it shows promise in its potential for alleviating sperm-related issues related to chemotherapy treatment in future research.

The World Health Organization has researched the use of astaxanthin as a complementary treatment for male infertility in humans. One study on infertile couples, in which the female did not exhibit signs of infertility, showed promising results when the male partners consumed astaxanthin supplements produced from microalgae.<sup>33</sup> Compared to males who received a placebo treatment, males who consumed 16 mg of astaxanthin daily for 3 months had significantly decreased markers of reactive oxygen species in the semen.<sup>33</sup> Furthermore, couples in which the male received astaxanthin also had a pregnancy rate of 54.5%, which was much higher than placebo couples at 10.5%.<sup>33</sup>

### Potential Toxicity and Harmful Side Effects

The United States Food and Drug Administration deemed astaxanthin extracted from *H. pluvialis* as “generally recognized as safe” in 2010.<sup>2</sup> Additionally, astaxanthin was approved as a food colorant in animal and fish feed in 1987, and as a nutraceutical in 1999.<sup>4, 22</sup>

To date, no adverse side effects of consuming astaxanthin have been reported in human studies.<sup>2</sup> The FDA has approved the use of astaxanthin produced from *H. pluvialis* for direct human consumption dosages up to 12 mg/day and up to 24 mg/day for no more than 30 days.<sup>6</sup> However, astaxanthin has been extensively researched in doses ranging from single large doses of 100 mg, 40 mg daily for 4 weeks, or daily doses of 4 mg for 12 months, without any reported negative side effects.<sup>2</sup> In animal models, doses over 120 mg/day have also not shown to have harmful effects.<sup>34</sup> Additionally, there is no risk of Vitamin A toxicity (hypervitaminosis A) from consuming astaxanthin.<sup>35</sup> Vitamin A toxicity is a concern when consuming carotenoid supplements, like beta carotene.<sup>35</sup> Beta carotene can be converted to Vitamin A in the liver, which can potentially build up to toxic levels when taken in large quantities. Because astaxanthin cannot be converted to Vitamin A molecules in the body, it is not toxic when consumed in large amounts.<sup>12</sup>

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# BRISTOL BAY SOCKEYE SALMON

## Astaxanthin: A Review of the Literature

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