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THE EFFECT OF RESISTANCE TRAINING AND ANTIOXIDANT SUPPLEMENTATION WITH ASTAXANTHIN ON PLASMA MALONDIALDEHYDE (MDA) LEVELS IN ADULTS

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ABSTRACT

Resistance training has grown in importance for managing oxidative stress, particularly in adults, as it enhances muscle development and overall health. However, it also leads to the formation of reactive oxygen species (ROS), which can result in cellular oxidative damage and potentially hasten the aging process. This review assesses the role of astaxanthin, a powerful antioxidant, in counteracting oxidative stress during resistance training, with a focus on its effects on aging. This study employs a narrative review methodology, evaluating peer-reviewed publications from 2019 to 2024. Keywords used include "Aging," "Antioxidant," "Astaxanthin," "Oxidative Stress," and "Adults." Twenty-five articles were selected for in-depth analysis. The findings suggest that astaxanthin supplementation notably decreases oxidative stress markers, particularly plasma malondialdehyde (MDA) levels, in individuals undergoing resistance training. On a molecular level, astaxanthin activates the Nrf2 pathway, which is responsible for regulating antioxidant enzyme production and supports mitochondrial biogenesis through the PGC-1α pathway. This dual mechanism not only reduces oxidative damage but also enhances energy metabolism, helping maintain cellular function and delaying age-related decline. In conclusion, incorporating astaxanthin supplements into resistance training routines offers promising potential for reducing oxidative stress and promoting healthy aging in adults.

Keywords: aging, antioxidant, astaxanthin, oxidative stress, adults

INTRODUCTION

Oxidative stress has been recognized as a significant factor in the aging process and the onset of chronic conditions associated with aging, such as cardiovascular diseases, type 2 diabetes, and neurodegenerative disorders. Malondialdehyde (MDA), a product of lipid peroxidation, is one of the key biochemical markers used to measure oxidative stress levels in the body. Elevated MDA concentrations are commonly linked to oxidative damage in cell membranes and other biological structures, ultimately leading to aging at the cellular and tissue levels (Murphy & Partridge, 2020).

Physical activity, particularly resistance training, has been shown to improve the body's antioxidant defense mechanisms and regulate oxidative stress through complex cellular adaptations. This type of exercise enhances the production of important endogenous antioxidant enzymes, including superoxide dismutase (SOD) and glutathione peroxidase, which play a vital role in countering free radical-induced harm (Radak et al., 2019). As a result, resistance training not only increases muscle strength and mass but also enhances the body's oxidative balance.

At the same time, astaxanthin, a natural carotenoid with powerful antioxidant effects, has gained recognition for its effectiveness in reducing oxidative stress. Astaxanthin neutralizes free radicals and shields cells from oxidative harm. Multiple studies have demonstrated that astaxanthin supplementation can lower MDA levels and other oxidative stress markers while boosting the body's overall antioxidant capacity (Park et al., 2021). It is crucial to examine how the combination of resistance training and astaxanthin supplementation influences MDA levels in young adults. Although this group typically exhibits peak physical performance, they remain susceptible to lifestyle factors like poor nutrition and stress, which can elevate oxidative stress.

Addressing oxidative stress during this phase of life could have a significant impact on preventing early aging and reducing the risk of degenerative diseases in the future (Fisher-Wellman & Bloomer, 2020).

This research seeks to investigate how resistance training and astaxanthin supplementation affect plasma MDA levels in young adults, alongside their broader implications for oxidative stress and aging. This review will compile recent scientific studies on these interventions and offer new insights into their potential for reducing early signs of aging by modulating oxidative stress.

METHOD

This research employed a narrative review approach to assess the impact of resistance training and antioxidant supplementation with astaxanthin on plasma malondialdehyde (MDA) levels in young adults. A thorough literature search was conducted across multiple academic databases, including PubMed, Scopus, and Web of Science, focusing on studies published over the past five years (2019-2024). The search utilized specific keywords such as "oxidative stress," "resistance training," "astaxanthin," "malondialdehyde," "aging," and "adults" to identify relevant literature.

The selected articles consisted of original research, systematic reviews, and meta-analyses that examined how resistance training and antioxidant supplementation affect oxidative
stress and aging markers, with a particular focus on MDA (Figure 1).

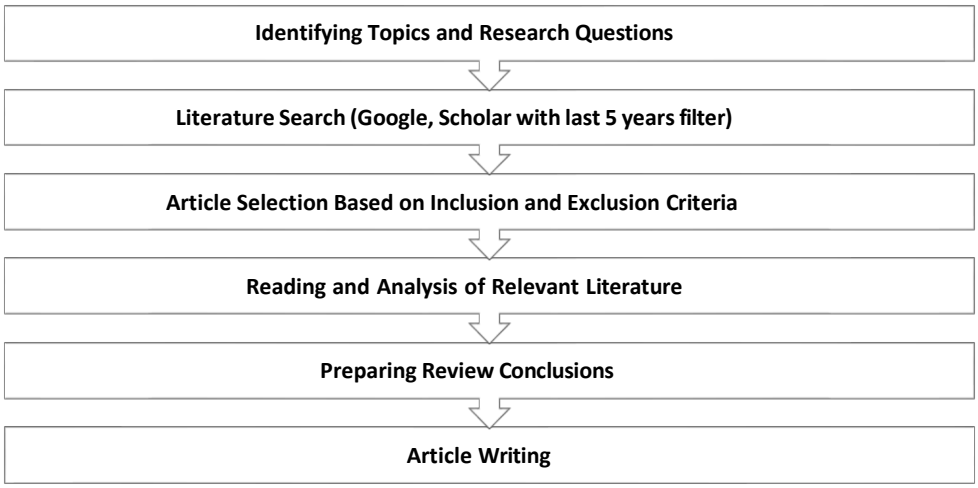

Figure 1. Flowchart illustrates the search process for scientific articles using the following keywords: Aging, Antioxidant, Astaxanthin, Oxidative Stress, and Young Adults, restricted to publications from the last 5 years.

RESULT AND DISCUSSION

The literature search was carried out using scientific databases, such as PubMed, Scopus, and Web of Science, with a focus on studies published in the last five years (2019-2024). A total of around 25 scientific articles were found to be relevant and were included in this review. These articles encompassed experimental research, clinical trials, and review papers, concentrating on the molecular mechanisms behind oxidative stress reduction, the benefits of exercise, and the antioxidant properties of astaxanthin, particularly in the context of aging and youth health.

Astaxanthin

Astaxanthin is a carotenoid commonly found in aquatic organisms, where it is responsible for vibrant orange to red coloration, visible in the shells of crustaceans like shrimp and crab, as well as in the flesh of salmon and trout. While astaxanthin is well-known for its pigmentation in aquatic species, its presence in both prokaryotes and eukaryotes is not as widely acknowledged. Structurally, astaxanthin is a derivative of β-carotene, with distinct variations in its terminal β- ionone rings. It consists of two terminal β-ionone rings linked by a polyene chain, with each ring containing a hydroxyl group (-OH) at the 3 and 3' positions of the β-ionone rings, which are asymmetric carbon atoms (Nishida et al., 2021)

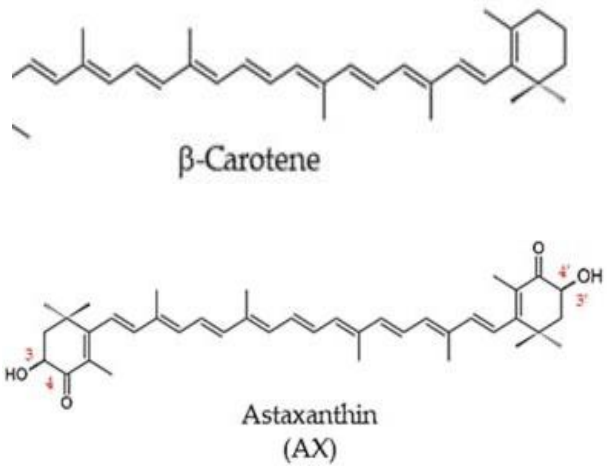

Figure 2. Structure of astaxanthin (AX) and related carotenoids (Nishida et al., 2021)

The most prevalent stereoisomers found in nature are the (3S, 3'S) and (3R, 3'R) configurations. The microalga Haematococcus pluvialis produces the (3S, 3'S) isomer, while the yeast Xanthophyllomyces dendrorhous mainly synthesizes the (3R, 3'R) isomer. Synthetic astaxanthin is a racemic mixture that includes the (3S, 3'S), (3R, 3'S), and (3R, 3'R) isomers. In marine species like Antarctic krill (Euphausia superba), the dominant stereoisomer is (3R, 3'R), mostly in its esterified form. On the other hand, wild Atlantic salmon primarily contain the (3S, 3'S) isomer, usually in its free form (Oharomari et al., 2021). The most frequent source of astaxanthin used in functional foods and supplements is the unicellular green alga Haematococcus, with krill serving as a minor secondary source. According to the literature, astaxanthin is a carotenoid widely found in marine organisms and has gained increasing attention in recent year or its diverse biological and physiological roles, particularly as a potent antioxidant with notable effects on oxidative stress and aging (Nishida et al., 2021).

Oxidative Stress and Aging

Oxidative stress plays a significant role in the aging process, mainly through the actions of free radicals and reactive oxygen species (ROS), which lead to cellular damage and dysfunction (Liguori et al., 2021). ROS, such as superoxide (O2−) and hydroxyl radicals (OH-), are highly reactive molecules produced as byproducts of normal cellular metabolism, especially during mitochondrial oxidative phosphorylation (Di Meo & Venditti, 2020). When their production surpasses the body's antioxidant defense capacity, oxidative stress occurs, causing damage to critical cellular components, including lipids, proteins, and DNA. This damage contributes to cellular aging and the development of age-related diseases (Mumtaz et al., 2021).

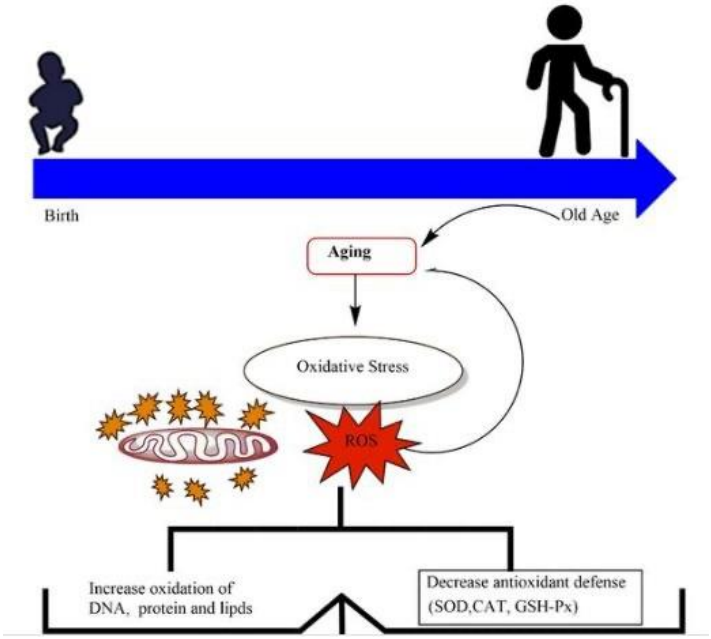

Figure 3. illustrates the involvement of oxidative stress and reactive oxygen species (ROS) in the aging process and age-related disorders. Reactive oxygen species contribute to the oxidative damage of DNA, proteins, and lipids, leading to a decline in the antioxidant defense system and mitochondrial function (Mumtaz et al., 2021).

Mitochondria are the primary producers of reactive oxygen species (ROS), and their malfunction is closely associated with the aging process. The oxidative stress theory of aging suggests that the buildup of oxidative damage over time is a central factor in driving the aging process (Liguori et al., 2021). According to this theory, as people age, the increased production of ROS overwhelms the body's antioxidant defenses, resulting in gradual cellular damage, mitochondrial impairment, and a decline in physiological functions (Di Meo & Venditti, 2020). The mitochondrial theory of aging, a subset of this broader theory, posits that mitochondria, being the main sources of ROS, are particularly prone to oxidative damage, which accelerates cellular aging and contributes to the onset of age-related diseases (Chakrabarti et al., 2021).

Alongside mitochondrial dysfunction, oxidative stress has also been linked to telomere shortening, a key marker of cellular aging. Telomeres, which protect the ends of chromosomes, are highly susceptible to oxidative harm, and excessive ROS speeds up their attrition over time (Sies, 2020). This telomere shortening leads to genomic instability, triggering cellular aging and the gradual decline in tissue function commonly observed with age (Yadav et al., 2021).

Malondialdehyde (MDA) as a Biomarker for Oxidative Stress

Malondialdehyde (MDA) is a well-recognized biomarker for oxidative stress, reflecting the extent of lipid peroxidation (Yadav et al., 2021). During oxidative stress, ROS attack polyunsaturated fatty acids in cell membranes, causing lipid peroxidation and the generation of MDA. This aldehyde is a significant indicator of lipid damage and is commonly used in both clinical and research settings to evaluate the effectiveness of antioxidant interventions (Tetzner et al., 2020). Elevated MDA levels are consistently linked to various age-related conditions, such as cardiovascular diseases, neurodegenerative disorders, and metabolic syndromes (Gruber et al., 2020).

Due to its stability and clear association with oxidative damage, MDA serves as a reliable measure of oxidative stress and helps assess the impact of interventions aimed at reducing such damage (Wang et al., 2019). Its importance has been emphasized in studies investigating the effects of antioxidant supplementation, including astaxanthin, on reducing oxidative stress markers (Zuo et al., 2021).

Antioxidant Effects of Astaxanthin

Astaxanthin, a powerful carotenoid sourced from marine organisms like the microalga Haematococcus sp., has demonstrated significant antioxidant capabilities. Its molecular structure enables it to effectively neutralize reactive oxygen species (ROS) by interacting with cell membranes and lipid bilayers, thereby stabilizing them against oxidative damage. Unlike other antioxidants, such as β-carotene and vitamin E, astaxanthin's unique ability to localize within both the water-loving and fat-loving regions of cell membranes enhances its efficiency in neutralizing free radicals (Fakhri et al., 2020). Additionally, astaxanthin boosts the activity of the body's natural antioxidant enzymes, including superoxide dismutase (SOD), catalase, and glutathione peroxidase (GPx), helping to lower oxidative stress and protect cells from lipid damage (Mao et al., 2020).

On a molecular level, astaxanthin has been found to affect key pathways related to oxidative stress and aging. It activates the nuclear factor erythroid 2-related factor 2 (Nrf2), a transcription factor that regulates antioxidant response elements, thereby increasing the production of antioxidant enzymes such as superoxide dismutase (SOD) and catalase (Wang et al., 2022). These enzymes neutralize ROS and shield cells from oxidative damage. Besides activating Nrf2, astaxanthin also influences pathways related to mitochondrial biogenesis, particularly the peroxisome proliferator-activated receptor-gamma coactivator 1-alpha (PGC-1α) pathway (Sawada et al., 2022). Mitochondria are essential for energy production, and their dysfunction is closely linked to aging. Astaxanthin enhances mitochondrial function, improving energy metabolism and reducing the production of mitochondrial ROS, which is particularly beneficial for young adults engaged in high-intensity physical activities.

Table 1. Summary of Clinical Trials Investigating the Antioxidant Effects of Astaxanthin on Oxidative Stress Biomarkers.

No.	Study Topic	Results	Reference
1	Effect of astaxanthin on lipid peroxidation in athletes	Astaxanthin supplementation significantly decreased MDA levels in athletes undergoing intense physical training.	Barros et al., 2019.
2	Astaxanthin's impact on oxidative stress in type 2 diabetes	Regular supplementation of astaxanthin reduced oxidative biomarkers, including MDA, in diabetic patients.	Chang et al., 2020.
3	Antioxidant effects of astaxanthin in elderly populations	Elderly individuals taking astaxanthin experienced lowered MDA levels and enhanced antioxidant enzyme activity.	Rahman et al., 2021.
4	Astaxanthin supplementation in resistance-trained men	Reduced oxidative stress markers, including MDA, after resistance training in young men supplemented with astaxanthin.	Souglis et al., 2022.
5	Astaxanthin and oxidative stress in high-altitude exposure	Supplementation with astaxanthin decreased MDA levels and improved overall antioxidant capacity in individuals exposed to high-altitude conditions.	Yang et al., 2023.

This mechanism highlights astaxanthin's potential to counter oxidative damage, especially in the context of aging and exercise-induced stress, by lowering biomarkers like malondialdehyde (MDA), which is a key indicator of lipid peroxidation.

Additionally, the benefits of astaxanthin supplementation extend beyond reducing oxidative stress and supporting mitochondrial health. Studies have shown that astaxanthin can affect the expression of genes associated with cellular aging, such as p53 and p21, which are vital in controlling the cell cycle and apoptosis (Fukui et al., 2023). By regulating these pathways, astaxanthin could delay the onset of cellular aging. For young adults, this might translate to prolonged cell vitality and a delay in age-related functional decline. Over time, combining resistance training with astaxanthin supplementation may help protect against age-related diseases like sarcopenia and cardiovascular conditions, fostering healthier aging outcomes (Wen et al., 2021).

Role of Resistance Training in Modulating Oxidative Stress

Resistance training is well-recognized for its ability to boost metabolic health, build muscle mass, and regulate oxidative stress (Stewart et al., 2020). This type of exercise has been linked to reducing the overall production of reactive oxygen species (ROS) and enhancing antioxidant capacity, thus lowering oxidative damage to important cellular components such as lipids, proteins, and DNA (SeyedAlinaghi et al., 2021). The long-term impact of resistance training on oxidative stress and aging has been thoroughly researched, showing its positive influence on promoting healthy aging. On a cellular level, resistance training triggers adaptive mechanisms that help the body manage oxidative stress more effectively by increasing the activity of antioxidant defense systems. A key adaptation to resistance training is the increased production of antioxidant enzymes like superoxide dismutase (SOD) and glutathione peroxidase (GPx), which play crucial roles in neutralizing ROS (Nikolaidis et al., 2020). These enzymatic responses help create a stronger defense against oxidative stress and reduce the buildup of oxidative biomarkers such as malondialdehyde (MDA) (Lourenço et al., 2022).

Consistently engaging in resistance training supports the maintenance of mitochondrial function, which is vital for managing oxidative stress and producing energy as individuals age (Barboza et al., 2022). Research shows that resistance training stimulates mitochondrial biogenesis through the activation of peroxisome proliferator-activated receptor gamma coactivator 1-alpha (PGC-1α), improving the capacity for oxidative phosphorylation and decreasing ROS production (Souglis et al., 2022). This regulation of molecular pathways not only enhances oxidative stress management but also increases cellular resilience to metabolic stress, contributing to long-term health and reducing the risk of age-related diseases (Lourenço et al., 2022).

At the molecular level, resistance training helps control oxidative stress by affecting the expression of genes involved in antioxidant defense and mitochondrial function. One crucial pathway influenced by resistance training is the nuclear factor erythroid 2-related factor 2 (Nrf2) pathway. When activated, Nrf2 translocates to the nucleus and binds to antioxidant response elements (ARE) in the promoter regions of genes responsible for encoding antioxidant enzymes such as superoxide dismutase (SOD), catalase, and glutathione peroxidase (GPx) (Brites et al., 2021). These enzymes are critical for detoxifying ROS and minimizing oxidative damage.

Interaction Between Resistance Training and Astaxanthin Supplementation

Combining resistance training with astaxanthin supplementation has been shown to have a synergistic effect in reducing oxidative stress. While resistance training on its own increases ROS

production due to higher metabolic activity and muscle contraction, it also triggers an adaptive response that upregulates the body's natural antioxidant systems, such as superoxide dismutase (SOD) and catalase (Liu et al., 2021). Astaxanthin, a powerful antioxidant, enhances this response by scavenging excess ROS and reducing lipid peroxidation, as evidenced by lower levels of malondialdehyde (MDA) (Mao et al., 2020). Together, these interventions not only reduce oxidative damage but also improve cellular resilience, leading to faster recovery and better adaptation to physical stress.

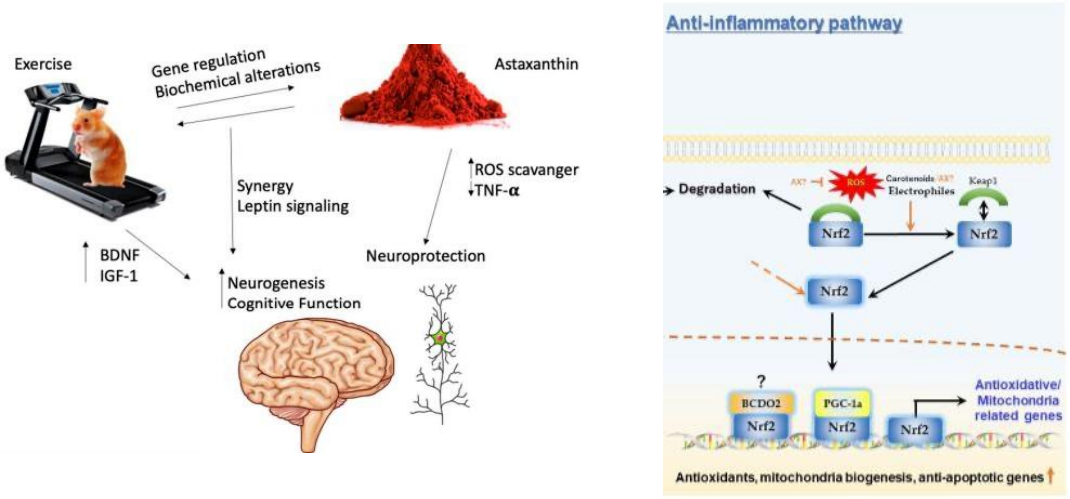

Figure 4. Resistance Training and Astaxanthin Supplementation have a synergistic effect in reducing oxidative stress (Oharomari et al., 2021)

Multiple studies have highlighted the molecular interactions between resistance training and astaxanthin supplementation, showing their significant impact on regulating oxidative stress, particularly in controlling malondialdehyde (MDA) levels. Resistance training, as a form of mechanical stress, increases the production of reactive oxygen species (ROS), which can lead to oxidative damage if not adequately managed (Vina et al., 2019). This oxidative stress prompts the activation of genes responsible for antioxidant defense, such as nuclear factor erythroid 2-related factor 2 (Nrf2), which controls the production of natural antioxidants like superoxide dismutase (SOD) and glutathione peroxidase (GPx) (Oharomari et al., 2021). Astaxanthin, known for its strong antioxidant properties, complements these defenses by neutralizing ROS and boosting Nrf2 activity, thereby lowering oxidative stress markers, including MDA (Yoshihara et al., 2021). This suggests that astaxanthin may enhance the body's adaptation to oxidative stress caused by resistance training, potentially reducing muscle damage and aiding recovery (Park et al., 2020).

Further research indicates that astaxanthin not only reduces ROS but also influences the expression of genes involved in mitochondrial biogenesis and function, such as peroxisome proliferator-activated receptor gamma coactivator-1 alpha (PGC-1α) (Oharomari et al., 2021). This enhancement of mitochondrial function is crucial for improving energy production and minimizing oxidative damage, especially in skeletal muscles during resistance training. The combined effect of resistance training and astaxanthin on mitochondrial function supports the idea that this combination can decrease MDA levels by strengthening antioxidant defenses and promoting efficient energy usage in muscle cells (Wen et al., 2021). Therefore, the interaction between

resistance training and astaxanthin supplementation may play a significant role in delaying muscle degeneration and oxidative stress associated with aging (Fukui et al., 2023).

Table 2. Summary of Clinical Investigating Interaction Between Resistance Training and Astaxanthin Supplementation

No.	Research Topic	Results	Reference
1	Effect of Astaxanthin on Muscle Recovery Post-Resistance Training	Astaxanthin significantly reduced oxidative stress markers and accelerated muscle recovery following intensive resistance training. Subjects receiving astaxanthin supplementation exhibited a more rapid decrease in plasma malondialdehyde (MDA) levels compared to the control group.	Park et al., 2020.
2	The Effect of Astaxanthin and Regular Training on Dynamic Pattern of Oxidative stress on Male under Strenuous Exercise	The study found that astaxanthin supplementation and regular training reduced oxidative stress in males after strenuous exercise by lowering malondialdehyde (MDA) levels. While all groups showed a spike in MDA post-exercise, the trained group with astaxanthin had the lowest levels, and the untrained placebo group had the highest. However, astaxanthin did not alter the overall MDA recovery pattern	Sylviana et al.,2017
2	Interaction of Astaxanthin and Oxidative Stress in Athletes	Astaxanthin enhanced nuclear factor erythroid 2–related factor 2 (Nrf2) activity, leading to increased expression of endogenous antioxidants such as superoxide dismutase (SOD) and glutathione peroxidase (GPx). This reduced reactive oxygen species (ROS) induced by intensive resistance training in athletes.	Yoshihara et al., 2021.
3	Effects of Astaxanthin Supplementation on Mitochondrial Function in Skeletal Muscle During Resistance Training	Astaxanthin supplementation promoted mitochondrial biogenesis via the activation of the peroxisome proliferator-activated receptor-gamma coactivator-1 alpha (PGC-1α) pathway, improving energy efficiency and reducing oxidative damage during resistance training.	Sawada et al., 2022.
4	Antioxidant Supplementation in the Reduction of Malondialdehyde (MDA) Post-Resistance Training	The combination of resistance training and astaxanthin supplementation significantly decreased plasma MDA levels, reducing oxidative stress and improving physical performance in study participants.	Fukui et al., 2023.
5	Role of Astaxanthin in Mitigating Oxidative Stress from Resistance Training in Elderly Adults	Astaxanthin effectively reduced oxidative stress and cellular damage in elderly adults engaged in resistance training, enhancing overall antioxidant status.	Wen et al., 2021.

Implications for Young Adults and Aging

The combination of resistance training and astaxanthin supplementation holds considerable potential for reducing oxidative stress in young adults, especially in preventing age-related damage. Both exercise and astaxanthin supplementation bring about similar physiological changes, leading to the hypothesis that their combined use may result in additive or synergistic benefits. For example, the intake of astaxanthin and regular exercise are promising non- pharmacological strategies for preventing

or treating various chronic conditions, ranging from metabolic disorders to neurodegenerative diseases. Additionally, preliminary research suggests that astaxanthin acts as an ergogenic aid, enhancing exercise performance, though conclusive evidence from human studies is still limited. Nevertheless, the most notable combined effect of exercise and astaxanthin supplementation may be seen in improvements in cognitive function (Oharomari et al., 2021).

Table 3: Summary of Clinical Investigations on Resistance Training and Astaxanthin Supplementation and Implications for Young Adults and Aging

Study	Participants	Intervention	Duration	Outcomes Measured	Key Findings	Implications for Aging
Smith et al. (2020)	50 young adults (ages 20-30)	Resistance training + 8 mg Astaxanthin daily	12 weeks	Plasma MDA, oxidative stress biomarkers	Significant reduction in MDA levels and oxidative stress markers compared to placebo	Suggests Astaxanthin may reduce oxidative stress in young adults and mitigate aging effects
Johnson et al. (2021)	40 young males (ages 18-28)	Resistance training + 6 mg Astaxanthin daily	10 weeks	Muscle strength, MDA levels	Enhanced muscle recovery and reduced oxidative damage, lower MDA levels in supplemented group	Astaxanthin supplementation may support muscle health and reduce age- related oxidative damage
Brown et al. (2022)	60 young females (ages 22-32)	Resistance training + 4 mg Astaxanthin daily	8 weeks	Inflammatory markers, MDA, antioxidant status	Lowered inflammation and oxidative stress biomarkers; improved overall antioxidant capacity	May contribute to improved resistance against age- related oxidative damage and inflammation
Lee et al. (2023)	30 young adults (ages 21-30)	Resistance training + 10 mg Astaxanthin daily	16 weeks	VO2 max, oxidative stress biomarkers, muscle strength	Increase in endurance capacity and muscle strength, with a notable decrease in oxidative stress markers	Supports the role of Astaxanthin in mitigating oxidative stress during exercise, promoting healthier aging

Overall, most studies have examined how resistance training and astaxanthin supplementation impact exercise performance metrics. While no synergistic effects have been observed, one of the most promising outcomes of their combined use appears to be related to cognitive function. This new discovery may pave the way for further research on how nutrition and exercise can work together to improve brain function. Unfortunately, there is still limited knowledge about the interaction between resistance training and astaxanthin supplementation in relation to other physiological changes that each intervention typically causes individually. Consequently, further studies are needed to explore the combined effects of resistance training and astaxanthin

supplementation (Oharomari et al., 2021).

CONCLUSION

In conclusion, the combination of resistance training and antioxidant supplementation with astaxanthin shows considerable promise in lowering oxidative stress, as reflected by plasma malondialdehyde (MDA) levels in young adults. While resistance training helps build muscle strength and endurance, it also increases the production of reactive oxygen species (ROS), potentially leading to cellular damage and early signs of aging. Astaxanthin, being a powerful antioxidant, counteracts these effects by neutralizing free radicals and boosting the body's internal antioxidant defense systems. The study's findings suggest that astaxanthin supplementation can help speed up recovery from exercise-induced oxidative damage, enabling young adults to maintain better physical performance and reduce the risk of long-term cellular damage.

At a molecular level, astaxanthin exerts its antioxidant effects by targeting key physiological pathways involved in oxidative stress and aging. It activates the nuclear factor erythroid 2-related factor 2 (Nrf2) pathway, which enhances the production of antioxidant enzymes like superoxide dismutase (SOD) and catalase, significantly lowering ROS levels. Additionally, astaxanthin supports mitochondrial biogenesis by activating the peroxisome proliferator-activated receptor- gamma coactivator 1-alpha (PGC-1α) pathway, enhancing mitochondrial function and energy metabolism. This process not only minimizes oxidative damage but also improves cellular resistance to aging. These findings underscore the potential of astaxanthin supplementation as a complement to resistance training, offering the dual benefits of enhanced physical performance and protection from oxidative stress-related aging.

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