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Original Article

Extra virgin olive oil as a functional food for athletes: recovery, health, and performance

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Abstract
Extra virgin olive oil, a cornerstone of the Mediterranean diet, has been recognized for its richness in bioactive compounds, particularly polyphenols, that have conferred many health benefits. This narrative review examined the role of olive oil in mitigating oxidative stress and inflammation, with a specific focus on its impact on athletes and sports performance. The phenolic compounds in olive oil, including hydroxytyrosol, tyrosol, oleocanthal, and oleuropein, were found to show antioxidant, anti-inflammatory, and cardioprotective properties, making olive oil a potential dietary intervention for enhancing recovery and resilience in athletes. Studies reviewed have highlighted extra virgin olive oil for its ability to protect red blood cells from oxidative damage, preserve cardiovascular function, and improve muscle recovery. Olive oil supplementation has also been linked to reduced markers of oxidative stress and inflammation, improved aerobic ability, and enhanced muscle strength in both recreational and professional athletes. Mechanistically, its polyphenols have been shown to modulate mitochondrial function, improve antioxidant enzyme activity, and promote metabolic efficiency during physical activity. Despite promising evidence, variability in study methodologies, dosages, and populations has limited definitive conclusions. Additionally, current evidence suggests that while olive oil may contribute to endurance and recovery, further investigation is needed to determine its specific role in different sports disciplines. While olive oil has shown potential in endurance and recovery contexts, its acute performance-enhancing effects have still been less clear. Future research should aim at standardizing protocols and exploring the long-term impact of olive oil supplementation on diverse athletic populations. This review underscores the potential of olive oil as a natural and sustainable strategy in sports nutrition, supporting physical performance and recovery while contributing to overall health.
Key Words: **erythrocytes, hydroxytyrosol, Mediterranean diet, olive oil, oxidative stress, polyphenols, reactive oxygen species.**

Introduction

Olive oil, a cornerstone of the Mediterranean diet for centuries, is one of the most extensively studied foods for its beneficial effects on human health. In particular, extra virgin olive oil (**EVOO**), the purest and least refined form, stands out for its high content of nutrients and bioactive compounds that provide a wide range of health benefits (Boskou & Clodoveo, 2020; Tian, Bai, Tian, & Zhao, 2023). Among these are the reduction of cardiovascular disease risk, protection against cancer, and slowing of cellular aging processes (Ditano-Vázquez et al., 2019; Farràs et al., 2021). These properties are primarily attributed to the presence of phenols and polyphenols, powerful antioxidants that effectively counteract oxidative stress (**OS**), a key factor in cellular aging and the onset of chronic diseases (Manna et al., 2002; Serreli & Deiana, 2020; D'Angelo et al., 2009; Boccellino & D'angelo, 2020; Boccellino et al., 2021).

EVOO, derived from the pressing of olives, is characterized by a high concentration of monounsaturated fatty acids, with oleic acid including 55-83% of its total composition. Monounsaturated fatty acids are associated with numerous cardiovascular benefits, including the reduction of LDL (Low-Density Lipoprotein) cholesterol levels (Schwingshackl & Hoffmann, 2012). However, the unique value of EVOO lies in its phenolic compounds, such as hydroxytyrosol (**HT**), tyrosol (**TYR**), oleocanthal (**OLC**), and oleuropein (**OLE**). Although these compounds constitute a minor fraction of its composition, they play a crucial role due to their antioxidant, anti-inflammatory, and biological properties, interacting with complex molecular mechanisms to modulate OS and inflammatory responses (D'Angelo et al., 2020a).

OS occurs when there is an imbalance between the production of reactive oxygen species (**ROS**) and the ability of endogenous antioxidant systems to neutralize them (Sies, 2015). The accumulation of ROS can damage DNA, proteins, and lipids, accelerating cellular aging and contributing to the development of chronic diseases (Halliwell, 2022). Cellular aging is a complex phenomenon involving a progressive decline in the ability of cells to respond to environmental stimuli (Li et al., 2023). This phenomenon is particularly harmful to highly sensitive cells, such as erythrocytes (**RBC**), which play an essential role in oxygen transport and carbon dioxide removal

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(Koch et al., 2019). Due to their direct involvement in oxygen transport, RBC are especially vulnerable to OS. Oxygen itself can promote the formation of reactive species, such as free radicals, that attack cellular membranes and internal structures, compromising their functionality. Damaged RBC not only reduce the efficiency of oxygen transport but also exacerbate cardiovascular risk (Lee, Huang, & Wang, 2015). Specifically, the reduced oxygen-carrying ability of RBC and their impaired flexibility slow blood flow in micro vessels. This limits tissue oxygenation, increasing the workload on the heart to support adequate perfusion. Altered RBC release free hemoglobin and iron, which amplify ROS production in the endothelium (Violi et al., 2017).

Finally, oxidized RBC can activate endothelial cells and leukocytes, contributing to chronic inflammation (Haybar, et al., 2019). This process worsens vascular conditions and accelerates atherosclerosis progression. Moreover, oxidative damage directly affects the cardiovascular system by impairing endothelial function and further promoting atherosclerotic processes. ROS reduce the bioavailability of nitric oxide (**NO**), a potent vasodilator. As a result, peripheral vascular resistance increases, and arterial stiffness is exacerbated (Tousoulis, et al., 2012).

RBC alterations also affect skeletal muscle by reducing oxygenation and impairing ATP production, which is essential for muscle contraction and recovery. The resulting hypoxia shifts metabolism toward anaerobic pathways, increasing lactate production and leading to local acidosis (Ellsworth & Sprague, 2012). Additionally, skeletal muscle can suffer direct OS damage, particularly during intense physical exercise. Indeed, ROS release can alter mitochondrial function and activate protein degradation processes, such as the action of calpains and caspases (Jang et al., 2020). Furthermore, poor oxygenation slows muscle regeneration processes (Chatzinikita et al. 2023). This results in reduced muscle strength, delayed recovery, and increased fatigue feeling. At the molecular level, oxidative damage compromises the muscle's ability to efficiently utilize energy (Gomes et al., 2017). This vicious cycle involving damaged RBC, skeletal muscle, and the cardiovascular system highlights the complexity of OS role in chronic diseases and aging processes (**Fig. 1**). Physical activity, especially at high intensity, adds another layer of ROS production, amplifying the risk of muscle damage and early fatigue. Increased OS during exercise is a complex phenomenon. During physical activity, the heightened energy demand in muscles accelerates mitochondrial metabolism, promoting excessive ROS production (Powers et al., 2020). If not adequately balanced by antioxidant defenses, this can reduce blood flow and nutrient delivery to tissues, promote cardiac arrhythmias, and amplify physiological stress.

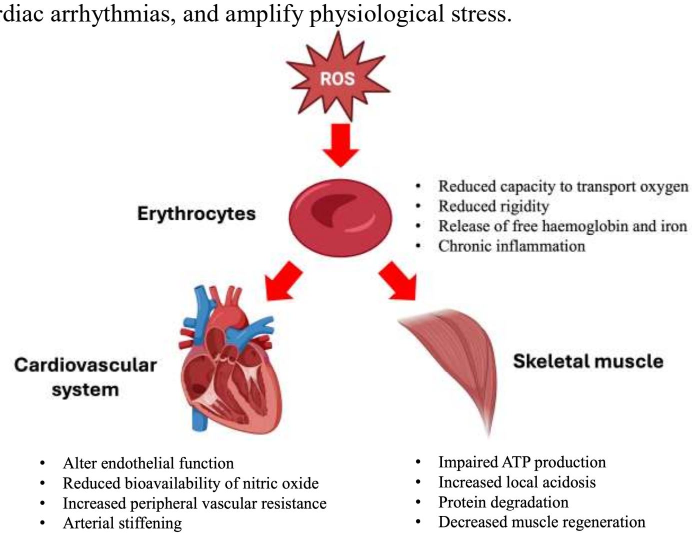

Fig.1 Effect of ROS on RBC, cardiovascular system and skeletal muscle

Given the increasing awareness of OS as a major factor in aging and disease, it is essential to identify effective strategies to counteract its effects. Current interventions often rely on pharmacological antioxidants or synthetic compounds, which may present limitations such as inconsistent efficacy or potential side effects. This highlights the need for natural, diet-based approaches that can provide long-term benefits without adverse consequences. EVOO, thanks to its rich antioxidant profile, is a promising candidate for such an intervention.

Clinical studies have shown that regular EVOO consumption is associated with reduced markers of inflammation and oxidation, with significant effects in preventing chronic diseases such as cardiovascular, neurodegenerative, and metabolic disorders (Manna et al., 2002; Notariale et al., 2022). Moreover, EVOO protects RBC cell membranes from lipid peroxidation, preserving their functionality and reducing the occurrence of cardiovascular complications (Perrone et al., 2023). Finally, the antioxidants in EVOO enhance the body's ability to adapt to physical stress, making it an ideal possibility for athletes and individuals engaged in intense sports activities. Regular EVOO consumption not only supports muscle recovery but also reduces post-exercise inflammation, improving the body's overall resilience. Through its modulatory action on inflammation and OS, EVOO is a natural and effective solution for promoting health and improving physical performance.

To investigate these effects, this research conducted a comprehensive review of the literature, selecting clinical and experimental studies that examined the impact of EVOO on OS biomarkers, inflammation markers, and physiological responses in athletes. The goal was to synthesize existing evidence and identify gaps in the current understanding of EVOO potential role in sports nutrition. Furthermore, by comparing different study methodologies and dosages, this review aimed to provide insights into the optimal use of EVOO for enhancing performance and recovery.

Main phenols of olive oil

EVOO is a valuable source of polyphenols that, despite their low concentration compared to lipid components, play a crucial role in promoting health and preventing chronic diseases.

One of the most studied polyphenols is HT, a simple phenol characterized by a benzene ring with two hydroxyl groups and an ethanol group. The presence of two hydroxyl groups makes HT particularly reactive against free radicals, granting it powerful antioxidant properties. This compound protects cells from ROS-induced damage, thereby reducing the risk of cardiovascular and neurodegenerative diseases (D'Angelo et al., 2001; Notariale et al., 2022). Numerous studies have demonstrated that HT can cross cellular membranes, protecting brain cells and contributing to the prevention of conditions such as Alzheimer's disease (Tabanez et al., 2023). Its strong antioxidant capacity helps prevent lipid peroxidation and DNA damage (D'Angelo et al., 2005; Perrone et al., 2024). In RBC, this compound reduces membrane oxidation, improving stability and prolonging functional lifespan. This action is particularly relevant in the context of OS induced by intense physical exercise, where RBC play a crucial role in oxygen transport.

TYR also owns antioxidant and anti-inflammatory properties, albeit less potent than HT due to the presence of only one -OH group. Nevertheless, TYR significantly contributes to cardiovascular protection by preserving cell wall integrity and reducing the risk of lipid peroxidation (Notariale et al., 2022). This slows cellular aging and enhances RBC resilience under stress conditions. Additionally, TYR exhibits neuroprotective effects, modulating dopamine levels and positively influencing mood and motivation, key factors for athletes requiring high mental focus during competition (Vauzour, Corona, & Spencer, 2010).

OLC is another distinctive phenolic compound in EVOO, characterized by the presence of an aldehyde (-CHO) group and an ethoxy group, which confer anti-inflammatory and analgesic properties (González-Rodríguez et al., 2023). This compound acts by inhibiting cyclooxygenase enzymes (COX-1 and COX-2), reducing the production of inflammatory molecules (Siddique et al., 2020). OLC shows activity like that of nonsteroidal anti-inflammatory drugs, such as ibuprofen, but without significant side effects. This property makes it particularly appealing for athletes, as it can alleviate muscle and joint inflammation associated with intense physical activity. Furthermore, OLC provides neuroprotective support, enhancing cognitive function and focus, key elements for optimizing athletic performance (Parkinson & Keast, 2014).

OLE, a polyphenol found in olive leaves and fruits, has a complex structure including a glucoside group, a hydroxylated ring, and ester groups. This compound is renowned for its potent antioxidant, anti-inflammatory, and cardioprotective effects (Ahamad et al., 2019). OLE helps reduce LDL cholesterol levels and improve insulin sensitivity, optimizing the energy metabolism of muscle cells (Micheli et al., 2023). For athletes, this translates to more efficient glycogen use and improved performance during endurance exercises or high-intensity activities. Recent studies have highlighted that OLE reduces exercise-associated oxidative damage, protecting muscles and RBC from OS (Nasrallah et al., 2020). Its ability to mitigate muscle damage and support energy metabolism makes OLE essential for post-training recovery and tissue protection. Additionally, OLE has shown promising effects in counteracting cellular OS and reducing systemic inflammation, key aspects for enhancing physical and mental resilience in athletes (Sun et al., 2017). Furthermore, this compound has been shown to promote programmed cell death (apoptosis) in cancer cells, expanding its potential as a protective and preventive agent not only in sports but also for overall health (Rishmawi et al., 2022).

Overall, the polyphenols in olive oil work synergistically to modulate oxidative and inflammatory processes, protecting cells from OS and improving cardiovascular, muscular, and cognitive functions (**Table 1**). These effects are particularly relevant for athletes, as they contribute to enhanced physical performance, accelerated recovery, and long-term health preservation.

Material & methods

A narrative review of the literature was conducted on the effect of EVOO supplementation in the diet of athletes to improve physical performance. The databases consulted included SCOPUS, Google Scholar, and PubMed (MEDLINE). Articles were selected based on title screening, year of publication (between 2010 and 2024), abstract review, and full-text reading to assess relevance. Added criteria included studies evaluating physical performance tests, such as aerobic, anaerobic, strength, power, or speed tests, conducted on athletes to decide performance differences. Articles involving participants who were not in good health were excluded. The keywords used in the search included a combination of terms: "exercise", "physical activity", "performance", "olive oil", and "polyphenols". Boolean operators "OR" and "AND" were taken into consideration alone or as combined terms, excluding duplicates. Articles without full-text access were not included in the final analysis. Studies were included and selected based on their relevance in associating physical performance with EVOO consumption.

Table 1. Main polyphenols of EVOO, characteristics, key biological functions, and relevance for athletes.

Polyphenol	Key Characteristics	Main Biological Effects	Relevance for Athletes
Hydroxytyrosol	- Simple phenol with two hydroxyl groups and one ethanol group. - Highly reactive and antioxidant.	- Protects against ROS-induced damage. - Prevents lipid peroxidation and DNA damage. - Reduces risk of neurodegenerative diseases.	- Stabilizes erythrocyte membranes, enhancing oxygen transport. - Reduces oxidative damage from intense exercise.
Tyrosol	- Phenol with one hydroxyl group. - Less potent antioxidant than hydroxytyrosol.	- Preserves cardiovascular health by reducing lipid peroxidation. - Neuroprotective by modulating dopamine levels.	- Supports mood and motivation, aiding mental focus during training. - Slows erythrocyte aging under stress.
Oleocanthal	- Complex structure with aldehyde (-CHO) and ethoxyl groups. - Anti-inflammatory and analgesic properties.	- Inhibits COX-1 and COX-2 enzymes, reducing inflammation. - Provides neuroprotection and mitigates chronic inflammation.	- Reduces muscle and joint inflammation. - Alleviates post-exercise soreness without side effects of nonsteroidal anti-inflammatory drugs.
Oleuropein	- Complex polyphenol with glucosidic, hydroxylated, and ester groups. - High bioavailability.	- Lowers LDL cholesterol and improves insulin sensitivity. - Protects against oxidative damage in muscles and erythrocytes. - Anti-tumor potential.	- Enhances glycogen utilization and energy metabolism. - Protects muscle tissue during intense or prolonged exercise.

Results

In recent decades, sports nutrition has broadened its scope, incorporating not only traditional macronutrients such as carbohydrates and proteins but also high-quality fats with potential metabolic and anti-inflammatory benefits (Morrison et al., 2015). Among these, EVOO stands out due to its richness in monounsaturated fatty acids and bioactive phenolic compounds, making it a central element of the Mediterranean diet. Its beneficial effects on cardiovascular health, lipid metabolism, and inflammation management are well-documented (Farràs et al., 2021). However, its potential impact on sports performance is less clear, being a topic of growing scientific interest.

The results obtained in this review provide a clearer picture of the relationship between EVOO consumption and various aspects of athletic performance, including oxidative stress modulation, recovery, endurance, and muscle function.

Specifically, while polyphenols are known for their role in neutralizing free radicals, their specific application in enhancing sports performance stays controversial. Preliminary studies suggest that these compounds may mitigate exercise-induced OS, accelerate muscle recovery, and potentially improve aerobic and anaerobic capacity (Elejalde, Villarán, & Alonso, 2021). However, scientific evidence is insufficient to definitively recommend the specific use of polyphenols in athletes' diets. Further research is needed to understand their impact on OS, antioxidant status, and to define the best dosing methods. An added complication is that most studies investigating the potential value and safety of supplements suggested to enhance athletic performance primarily involve well-trained athletes. As a result, little has been discussed about their value for recreational or occasional athletes. Despite their high training demands, athletes' diets may not have sufficient antioxidants to support their physical activity. In this context, the findings presented highlight how EVOO and its bioactive compounds could offer advantages in counteracting exercise-induced oxidative stress and supporting recovery, with evidence suggesting that EVOO supplementation enhances antioxidant capacity and reduces markers of muscle damage.

Another important issue is the wide variety of polyphenols present in foods, making it difficult to quantify their content and daily intake. Studies on flavonoids and other polyphenols suggest that consumption above 650 mg per day may reduce mortality risk compared to intake below 500 mg. Health benefits have been observed with doses between 500 mg and 1500 mg per day (Liu & Sesso, 2021). In summary, polyphenols represent an area of great interest in sports nutrition science, but greater clarity is needed regarding their specific effects, especially in relation to sports performance and recovery (D'Angelo, 2020b; D'Angelo & Cusano, 2020; D'Angelo & Cusano, 2020a; D'Angelo, 2023; Ferrara et al., 2022; Ferrara et al., 2023; Vuoso et al., 2020;

Ferrara et al., 2024; Ferrara et al., 2021). For this reason, the purpose of this review is to summarize scientific data on the effects of EVOO consumption on athletes and sports performance (**Table 2**).

Feng et al. studied the effects of HT on Sprague-Dawley rats subjected to intense physical exercise. Supplementation showed a significant improvement in exercise endurance and increased mitochondrial activation. HT counteracted the reduction in PGC-1α and the mitochondrial complex I subunit caused by excessive exercise, suggesting an enhancement of muscle bioenergetics. These results indicate that HT may be a potential modulator of mitochondrial function under conditions of severe physical stress (Feng et al., 2011).

Mikami et al. examined the effect of olive leaf extract on obesity, endurance ability, cognitive decline, and depression in a murine model. The observed benefits, such as improved exercise capacity and endurance, were attributed to the synergistic action of oleanolic acid and OLE, which modulate mitochondrial function and enhance antioxidant capacity (Mikami et al., 2021).

A 2022 study investigated the short-term impact of consuming a phytocomplex from olive fruit water rich in HT on OS markers in 29 recreationally active participants. Plasma malondialdehyde (**MDA**), superoxide dismutase (**SOD**), catalase (**CAT**), reduced glutathione (**GSH**), and HT levels were evaluated at rest, at once post-exercise, and at 1- and 24-hours post-exercise. After 16 days of supplementation, a reduction in post-exercise SOD activity and an increase in GSH were observed, indicating improved systemic antioxidant capacity (Roberts et al., 2022).

The same authors, in a 2023 study, examined the chronic effects of supplementation with this compound on submaximal and exhaustive exercise performance and respiratory markers of recovery. Twenty-nine participants completed a challenging aerobic exercise protocol. The data showed that HT reduced the time constant at the onset of exercise, running economy, and perceived exertion ratings. Additionally, HT led to modest improvements in acute recovery, showed by a shorter time reaching 50% of end-exercise levels. This paper highlights how phenolic compounds in EVOO, including HT and related metabolites, may provide benefits for aerobic exercise and acute recovery in recreationally active individuals (Roberts et al., 2023).

Lemonakis et al. examined the effect of OLE on young male athletes by analyzing their serum and urinary metabolome. To this end, nine healthy young males received either a commercially prepared extract or a placebo for one week, followed by a two-week washout period. Pathway analysis of the most affected metabolites revealed that tryptophan and acylcarnitine biochemistry were the most influenced. Additionally, several metabolites linked to indole metabolism were detected, potentially showing enhanced serotonin turnover. Phenylethylamine and related metabolites, as well as estrone, were associated with improved performance. Possible changes in the lipid profile and redox states of blood and urine were also studied (Lemonakis et al., 2022).

Upper respiratory tract infections (**URI**) have a significant impact on both training and competition in a sports context. Olive leaf extract is a supplement having high concentrations of polyphenols, particularly OLE and HT. Thirty-two high school students who played for their school’s elite sports team were recruited for a randomized controlled trial. The results showed a significant 28% reduction in sick days when supplemented with olive leaf extract. The dietary intake of these athletes was suboptimal for immune support. While olive leaf extract supplementation over the course of a season did not significantly reduce the incidence of URI, it shortened its duration, potentially facilitating a quicker return to play (Somerville, Moore, & Braakhuis, 2019).

Various scientific studies also prove that direct consumption of EVOO can enhance the physical performance of various athletes. Specifically, *Esquius et al.* evaluated the effect of EVOO supplementation on endurance performance. However, since the benefits of EVOO are systemic, the authors proposed analyzing its effects using variables that reflect coordination between physiological systems, as its efficacy might not be adequately assessed through the maximal or threshold parameters commonly used to measure performance and physiology. The goal of this research was to examine the effect of acute EVOO supplementation on cardiorespiratory coordination (**CRC**) and performance. The study included three exercise testing sessions, each separated by a 7-day interval. Cardiorespiratory coordination was evaluated through principal components analysis of specific cardiovascular and cardiorespiratory variables. Statistically significant differences in principal elements eigenvalues appeared between dietary interventions during moderate-intensity exercises. EVOO supplementation improved CRC during moderate-intensity exercise, although it did not influence performance or other physiological markers (Esquius, Garcia-Retortillo, Balagué, Hristovski, & Javierre, 2019).

A study by *Helvaci et al.* explored the effects of a 15-day EVOO-based diet, aligned with Mediterranean dietary principles, on physical performance, lactate clearance, anthropometric measures, and body composition. Fifteen male professional cross-country skiers taken part in this experimental study. Athletes’ performance was evaluated using a vertical jump test, hand grip strength test, 20-meter shuttle run test, and the Borg fatigue scale. The dietary intervention led to significant improvements in various parameters. Vertical jump height and hand grip strength increased. Shuttle run test duration, total distance covered, number of completed shuttles, and maximum oxygen consumption (VO_2 max) also improved. Additionally, athletes’ perceived fatigue scores decreased during different phases of the shuttle run test. However, lactate clearance time and body composition showed no significant changes between repeated measurements. Among anthropometric measurements, a reduction in upper arm circumference was observed. These results suggest that the Mediterranean diet is a safe and effective nutritional approach to improving aerobic performance and muscular strength. Optimal recovery is crucial for athletic performance, as it is during this phase that exercise adaptations occur. Lactate accumulation during exercise contributes to muscle fatigue, impairing the ability to sustain high performance during next training sessions. The rate of lactate clearance is therefore a key indicator of recovery. The Mediterranean diet, rich in antioxidants, polyphenols, and alkaline foods, may support lactate clearance. Fruits and vegetables, abundant in this diet, contribute to reducing dietary acid load. Earlier studies have highlighted the benefits of alkaline and Mediterranean diets on physical performance. This study hypothesized that a low acid, isocaloric approach based on Mediterranean dietary principles could significantly improve aerobic performance, anaerobic power, fatigue feeling, and recovery in adolescent athletes. It is known that young athletes tend to show lower adherence to the Mediterranean diet, making them ideal candidates for targeted nutritional interventions (Helvacı et al., 2023).

Adequate nutrition before an endurance race is crucial for sustaining exercise intensity. However, it is still unclear whether diet can influence exercise-induced muscle damage (**EIMD**) or exercise-induced cardiac stress (**EICS**). The study published in 2020 by *Mielgo-Ayuso et al.* aimed to examine the associations between EIMD, EICS, and the dietary habits of endurance athletes during the week leading up to a marathon. At the end of the race, blood samples were collected from 69 male athletes to measure levels of creatine kinase (**CK**), myoglobin, and creatine kinase-muscle brain isoform, markers of EIMD, as well as NT-proBNP (N-terminal pro b-type natriuretic peptide), troponin I (**TNI**), and troponin T (**TNT**), indicators of EICS. A stepwise regression analysis was used to evaluate the associations between EIMD, EICS, and the intake of specific food groups.

The results showed that meat consumption during the preceding week was positively associated with post-race levels of CK and myoglobin. Conversely, vegetables were negatively associated with CK levels. Additionally, the consumption of butter and fatty meat was positively correlated with post-race NT-proBNP and TNI values. On the other hand, fish consumption was associated with lower levels of CK, TNI, and TNT. Finally, EVOO demonstrated a protective effect, being negatively associated with post-race TNI and TNT values. This work thus highlighted that the consumption of meat, butter, and fatty meat was associated with increased muscle damage and cardiac stress after the marathon. Conversely, the intake of fish, vegetables, and EVOO could have a protective effect. A well-planned diet before a marathon might therefore help reduce the acute physiological stresses associated with this type of competition (Mielgo-Ayuso et al., 2020).

Endurance training improves physical performance and insulin sensitivity, likely due in part to increased fat oxidation. Since n-3 and n-9 unsaturated fatty acids can stimulate fat oxidation, *Boss et al.* hypothesized that a diet rich in these fatty acids could amplify the benefits of endurance training on physical performance, insulin sensitivity, and fat oxidation. To test this hypothesis, 16 sedentary, normal-weight men were randomly assigned to an isoenergetic diet enriched with EVOO and followed a 10-day progressive endurance training protocol. However, the data presented in this study showed that an olive oil-enriched diet does not seem to substantially enhance the effects of a short-term endurance training protocol in healthy young adults. This study clarified the limitations of short-term interventions (Boss et al., 2010).

Another study from 2016 showed that EVOO-based functional beverages enriched with α-tocopherol and docosahexaenoic acid (**DHA**) could provide valuable support for modulating OS and improving physical performance in athletes (Capó et al., 2016). Specifically, this study aimed to evaluate the effects of supplementation with such beverages on various aspects: physical performance, plasma and RBC fatty acid profiles, polyphenol levels, oxidative and nitrative damage, and antioxidant and mitochondrial gene expression in young and senior athletes. The athletes completed maximal exercise tests before and after one month of dietary supplementation. The results showed that the beverages did not influence performance parameters during maximal exercise. However, supplementation altered the lipid profile, increasing the concentration of polyunsaturated fatty acids and reducing saturated fatty acids in plasma, and raising DHA levels in RBC. Additionally, while basal plasma polyphenol levels remained stable, an increase in polyphenol concentration in blood cells was observed in senior athletes. From an OS-perspective, supplementation showed a protective effect. Finally, the beverages improved the gene expression of antioxidant enzymes in peripheral blood mononuclear cells after exercise in young athletes.

A 2019 study aimed to analyze the association between adherence to the Mediterranean diet, physical fitness, and body composition among Spanish university students (Cobo-Cuenca et al., 2019). The investigation involved 310 university students, collecting data on anthropometric variables, body composition, and physical fitness. Muscle strength was measured using handgrip dynamometry and the standing broad jump test, while cardiorespiratory fitness (CRF) was evaluated with the Course-Navette test. The results showed that EVOO consumption was associated with higher levels of muscle strength and CRF, highlighting the importance of a balanced diet for health and physical performance.

EVOO and its phenolic compounds are an intriguing area of research for improving sports performance. Preclinical and clinical studies suggest positive effects on OS, recovery, and aerobic ability, but the available evidence is still limited and inconsistent. Further studies are needed to better understand the interactions between EVOO, polyphenols, and exercise physiology, as well as to define best dosing protocols and practical applications for athletes at various levels.

Discussion

OS and inflammation are inevitable physiological processes associated with physical activity, particularly during intense or prolonged exercise (Powers et al., 2020). While these processes are necessary for the body's adaptation, excessive levels can cause muscle damage, slow recovery, and impair performance.

Physical exercise is a scenario where free radicals play a dual role. At low concentrations, ROS act as intracellular signals, promoting positive adaptations such as increased mitochondrial ability and muscle regeneration. However, excessive production can cause molecular damage, prolong inflammation, and hinder muscle recovery (Brieger et al., 2012). The correlation between OS and inflammation is particularly evident in physical activity: following intense training, the inflammatory response necessary for recovery can be amplified by high ROS levels, creating a vicious cycle of cellular damage and prolonged regeneration time (Clemente-Suárez et al., 2023). This underscores the importance of finding ways to regulate ROS levels in order to optimize recovery and prevent chronic inflammation

Table 2. Effects of EVOO on sports performance, with main findings

Study	Population/Model	Intervention	Main Findings
Feng et al. (2011)	Sprague-Dawley rats	Hydroxytyrosol	Improved exercise endurance, mitochondrial activation, modulation of PGC-1α.
Mikami et al. (2021)	Murine model	Olive leaf extract	Enhanced exercise capacity, mitochondrial function, and antioxidant capacity.
Roberts et al. (2022)	Active participants (n=29)	HT-rich phyto-complex	Reduced SOD activity post-exercise, increased GSH, improved systemic antioxidant ability.
Roberts et al. (2023)	Active participants (n=29)	HT-rich phyto-complex	Reduced time constant at exercise onset, improved running economy and recovery.
Lemonakis et al. (2023)	Young male athletes (n=9)	Oleuropein	Modulated metabolome (tryptophan, acylcarnitine), enhanced serotonin turnover and performance.
Somerville et al. (2019)	High school athletes (n=32)	Olive leaf extract (OLE)	28% reduction in URI duration, support for recovery, protective effects on immune function.
Esquius et al. (2019)	Athletes (not specified)	Acute extra virgin olive oil supplementation	Improved cardiorespiratory coordination (CRC) during moderate exercise, no effect on maximal performance.
Helvaci et al. (2023)	Professional athletes (cross-country skiing, n=15)	Mediterranean diet enriched with olive oil	Improved VO_2 max, muscle strength, reduced perceived fatigue, no changes in body composition.
Mielgo-Ayuso et al. (2020)	Marathon runners (n=69)	Olive oil consumption and pre-marathon diet	Protective effect of olive oil on muscle damage (CK, myoglobin) and cardiac stress (TNI, TNT).
Boss et al. (2010)	Young sedentary men (n=16)	Olive oil enriched isoenergetic diet	No significant enhancement of resistance training effects physical performance, insulin sensitivity, or fat oxidation; highlighted limitations of short-term interventions.
Capò et al. (2016)	Young and senior athletes (not specified)	Functional beverages with olive oil, α-tocopherol, and DHA	Improved lipid profile, increased DHA in erythrocytes, protective effect on oxidative damage, enhanced antioxidant gene expression in young athletes; no effect on maximal performance.
Cobo-Cuenca et al. (2019)	Spanish university students (n=310)	Adherence to Mediterranean diet, including olive oil	Positive association between olive oil consumption, muscle strength, and cardiorespiratory fitness; highlighted importance of a balanced diet for physical performance.

Also studies on redox biomarkers, such as carbonyl proteins and MDA, confirm that physical activity induces OS (Del Rio, Stewart, & Pellegrini, 2005). This study further strengthens this evidence by showing the complex interaction between oxidative stress markers and recovery times post-exercise. However, scientific evidence also suggests that regular exercise stimulates antioxidant adaptations that improve redox homeostasis. This phenomenon is not uniform across individuals: subjects with low antioxidant ability show significant improvements after exercise, while those starting at higher levels may experience a reduction. Moreover, the intensity and type of exercise influence ROS production: moderate aerobic activity promotes a controlled increase in free radicals, fostering muscle adaptation, whereas intense anaerobic exercise can cause muscle micro-injuries, an increase in pro-inflammatory cytokines (TNF-α), and excessive inflammation (He et al., 2016). These individual differences in oxidative responses highlight the need for personalized approaches in exercise and supplementation. The human body can expand its antioxidant ability to manage these increases. Cytokine regulation plays an essential role in this balance: the production of pro-inflammatory molecules like IL-6 is balanced by the release of anti-inflammatory cytokines like IL-10, promoting recovery and muscle repair (Bhol et al., 2024).

These complex phenomena highlight the need for effective strategies to modulate redox homeostasis and inflammation, where EVOO could be a natural and sustainable intervention. EVOO due to its richness in polyphenols, is a natural resource to counteract the harmful effects of OS. These compounds not only act as direct antioxidants, neutralizing free radicals, but also modulate critical molecular mechanisms involved in the inflammatory response and tissue repair processes (Yubero-Serrano, Lopez-Moreno, Gomez-Delgado, & Lopez-Miranda, 2019). In this way, polyphenols promote the restoration of homeostasis and improve the body's physiological adaptation, accelerating recovery and reducing the risk of chronic damage.

This paper specifically focuses on the potential of EVOO's polyphenols to modulate both OS and inflammation, providing a promising natural solution for athletes aiming to improve recovery.

The protective role of polyphenols is based on several mechanisms. Among these, their ability to chelate transition metals prevents the formation of ROS through redox reactions, while the inhibition of pro-oxidant enzymes, such as NADPH oxidase and xanthine oxidase, further limits their production (Jomova et al., 2023). At the same time, polyphenols enhance the activity of endogenous antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPX), protecting DNA, proteins, and lipids from oxidative damage (Ighodaro & Akinloye, 2018). The combination of these effects positions EVOO as a valuable supplement for athletes engaged in high-intensity training, where antioxidant defense mechanisms are crucial for optimal performance and recovery.

Additionally, they improve mitochondrial function and positively influence cellular signaling, which are fundamental aspects for sustaining the high energy demands associated with intense physical activity (Clemente-Suárez, Martín-Rodríguez, et al., 2023). Introducing antioxidant-rich foods such as EVOO can thus effectively modulate these processes, promoting physical resilience and reducing the impact of OS. EVOO, therefore, shows significant potential in supporting muscle metabolism and recovery, making it an ideal choice to meet athletes' needs. However, the response to polyphenols may vary based on individual factors, such as the athlete's baseline state, training intensity, and environmental conditions, suggesting the need for personalized nutritional approaches to improve their benefits. Finally, combining EVOO with other functional compounds could amplify its effects, offering new prospects for integrated and personalized sports nutrition. Despite promising evidence, further research is essential to translate these findings into practical, evidence-based recommendations.

The results presented in this review thus highlight EVOO potential to mitigate exercise-induced OS and inflammation, thereby improving physiological resilience and recovery ability in athletes. However, interpreting these effects requires a critical evaluation of existing evidence, considering methodological limitations and practical implications.

Studies such as those by *Feng et al*. and *Mikami et al*. show that these compounds can modulate mitochondrial function and reduce oxidative damage, highlighting a possible improvement in energy metabolism during intense exercise (Feng et al., 2011; Mikami et al., 2021). The ability of these compounds to preserve RBC functionality and modulate post-exercise inflammatory responses appears promising, especially in the context of endurance sports and high-intensity activities. However, a deeper understanding of the interactions between different polyphenols and cellular processes is necessary to clarify the extent of the observed benefits.

The studies analyzed show that EVOO and its phenolic compounds can support muscle recovery by reducing post-exercise oxidative stress and inflammation. Data from *Lemonakis et al*. and *Helvaci et al*. support the idea that a diet rich in EVOO may improve muscle strength, aerobic capacity, and reduce perceived fatigue (Helvacı et al., 2023; Lemonakis et al., 2022). However, the impact on maximal performance remains uncertain, as studies like that of *Boss et al*. did not observe significant improvements in short-term performance parameters (Boss et al., 2010). This finding emphasizes that the benefits of EVOO may be more apparent in recovery rather than in acute performance, suggesting that its primary value lies in supporting long-term physical resilience.

One of the main challenges appearing from this review is the variability in supplementation protocols and studied populations. While some studies suggest specific dosages to achieve benefits, others show that EVOO efficacy may depend on factors such as training level, nutritional status, and intervention duration. For instance, the work by *Esquius et al*. highlights the need for more sensitive evaluation parameters to capture the systemic benefits of EVOO (Esquius et al., 2019). Furthermore, heterogeneity in preparation and administration methods (pure oil vs. specific extracts) complicates the identification of practical guidelines for athletes.

Despite the many promising indications, the available evidence is insufficient to formulate definitive recommendations. Most studies rely on small sample sizes and preclinical models, limiting the generalizability of results. Additionally, the use of indirect parameters to measure OS and inflammation introduces variability in results. Future studies should include diverse athletic populations and adopt more standardized study protocols to decide EVOO efficacy and that of its polyphenols.

Conclusions

This paper confirms that EVOO is a natural and effective possibility for improving athletes' health and supporting physical performance, particularly within the context of a Mediterranean diet. This aligns with the growing body of evidence suggesting that EVOO's polyphenolic compounds play a significant role in modulating oxidative stress and inflammation, both of which are critical factors for recovery and performance. However, its role in sports nutrition strategies requires further investigation. The promising effects observed in terms of post-exercise recovery and inflammation reduction make EVOO a valuable supplement, especially for athletes looking to optimize recovery times. The use of EVOO might be particularly suitable for endurance athletes and in post-exercise recovery contexts, but caution is needed when interpreting its short-term benefits or its application in power sports. While EVOO has shown promise in endurance-based contexts, more research is needed to determine its impact on high-intensity, anaerobic activities, where the demands on muscle repair and recovery differ significantly. EVOO and its phenolic compounds are an intriguing area of research in sports nutrition, with potential effects on OS, inflammation, and recovery. The dual action of EVOO's compounds, acting both as direct antioxidants and modulators of inflammatory responses, positions it as a multifaceted tool in athletic nutrition, offering a potential approach to both prevention and recovery. However, the heterogeneity of the evidence highlights the need for more robust studies to define the best supplementation protocols and better understand the dynamics between nutrition, metabolism, and exercise physiology. The variability in results seen across different studies underscores the importance of personalized nutrition strategies, considering factors such as an athlete's baseline antioxidant capacity, training regimen, and individual response to supplementation. Future research should focus on longitudinal studies, multidisciplinary approaches, and biomarker analysis to confirm the benefits and translate them into practical recommendations for athletes and active populations. Such studies could lead to more targeted, evidence-based guidelines, which would be crucial for developing practical nutrition plans tailored to various athletic needs and training intensities.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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