THE IMPACT OF SUPPLEMENTATION WITH POMEGRANATE FRUIT (PUNICA GRANATUM L.) ON SPORT PERFORMANCE

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Abstract
Foods and supplements high in polyphenols are gaining popularity within sports nutrition. Polyphenols represent the most abundant dietary source of antioxidants and are part of an emerging field of nutraceuticals based on their biological activity and potent treatment effects in clinical conditions associated with oxidative stress and inflammation. Pomegranate (Punica granatum L.), one of the oldest known edible fruits, is nowadays broadly consumed throughout the world. Its fruits and seed are rich in numerous bioactive compounds, as polyphenols, and therefore, the scientific interest in this plant has been constantly growing in recent years. Pomegranate and its extracts have been shown to have health benefits relating to their antioxidant and anti-inflammatory properties. Using data obtained from PubMed and Scopus, this article provides a brief overview of the experimental evidence on intake pomegranate to improve exercise performance in humans.

Key words: pomegranate, polyphenols, oxidative stress, nutrition, sport performance.

Introduction
Pomegranate (Punica granatum L.), belonging to Punica L. genus, Punicaceae family, is an ancient fruit native to Central Asia in regions spanning from Turkmenistan to Iran and northern India as well as in the Middle East and the Mediterranean area (Holland et al., 2009). Pomegranate is nowadays also cultivated in subtropical Africa as well as in California, Arizona, and Mexico, in fact this plant requires high exposure to sunlight during summer and temperature not lowers than ~12°C in winter (Levin, 2006; Holland et al., 2009).

Pomegranate (POM) is a red, seeded, fleshy fruit which was recommended in traditional medicine to treat various inflammatory conditions. In modern-day research, the health benefits of POM have been associated to its high concentration of polyphenol compounds and nitrates (NO₃⁻), and consumption of POM juice (POMJ) or extract has been linked to a reduction in cancer proliferation, the amelioration of cardiovascular disease markers and joint inflammation. Recent studies have showed that POM-based supplements can also improve performance during aerobic exercise by enhancing the matching of vascular O₂ provision to muscular requirements (Wang et al, 2018; Danesi et al, 2017; Landete, 2011).

Discussion
Bioactive Constituents of Pomegranate
Pomegranate is a source of numerous polyphenolic compounds; POMJ contains a greater concentration of polyphenols (~3.8 mg.ml⁻¹) than other polyphenol-rich beverages such as red wine (~3.5 mg.ml⁻¹), cranberry juice (~1.7 mg.ml⁻¹) and Concord grape juice (~2.6 mg.ml⁻¹) (Fischer et al., 2011; Ambigaipalan et al., 2016).

Some clinical intervention researches support the theory of some cardiovascular benefits arising from polyphenol-rich beverages (red wine, tea and cocoa). In fact, epidemiological evidence suggests that polyphenols, at least in part, might explain the cardiovascular benefits from increased vegetable and fruit (Grassi et al., 2010). Polyphenols have several biological effects (D’Angelo et al., 2012a; D’Angelo et al., 2017; D’Angelo et al., 2019b; Martino et al., 2019) and in particular, they are antioxidants (D’Angelo et al., 2009; Zappia et al., 2010; D’Angelo & Sammartino, 2015). Polyphenols are part of an emerging field of nutraceuticals based on their biological activity and potent treatment role in clinical conditions associated with oxidative stress and inflammation including cardiovascular disease, type 2 diabetes, atherosclerosis, cancer, and rheumatoid arthritis (Williamson, 2017; Motti et al., 2018; D’Angelo et al., 2019c).

The pomegranate fruit includes bioactive molecules such as hydrolysable tannins (ellagitannins and gallotannins), ellagic acid and its derivatives, gallic acid, anthocyanins, proanthocyanidins, vitamins,
flavonoids, as well as lignans, sterols, saccharides, fatty acids, organic acids, terpenes and terpenoids (Wang et al., 2018). The polyphenols are predominantly from the ellagitannin subclass (80–90%) with smaller amounts of anthocyanins (8–15%) and POM has a potent antioxidant effect that is three times higher than the well-known antioxidant capacity of green tea or red wine. Punicalagin, belonging to the ellagitannin subgroup, is a bioactive molecule responsible for more than 50% of the juice’s potent antioxidant capacity, but the content of polyphenols in commercial pomegranate juices varies according to variety and industrial manufacturing process with considerable variability in the punicalagin content (Adams et al., 2006; Fischer et al., 2011; Borges and Crozier, 2012). Anthocyanins present in pomegranate comprise especially delphinidin, pelargonidin, cyanidin, and their glucosides (Alighouri et al., 2008; Fischer et al., 2013; Lantzouraki et al., 2015), and the typical colors of pomegranate fruits are attributed to them. Pomegranate seeds contain various fatty acids with the most represented punicic acid (Pande and Akoh, 2009; Verardo et al., 2014; Górnaś and Rudzinska, 2016; Ricci et al., 2006) (Fig. 1).

**Effects of Pomegranate**

Accumulating data clearly claimed that pomegranate, described as the new “super fruit”, has several health benefits. Pomegranates can help prevent or treat various disease risk factors including high blood pressure, high cholesterol, oxidative stress, hyperglycemia, and inflammatory activities. In fact, supplementation in pomegranate juice (POMj), having high levels of polyphenols, was shown to: reduce free radicals, oxidative stress and lipid peroxidation (-65%) (Kelawala et al., 2005), reduce risk of cardiovascular diseases by reducing high systolic blood pressure (-12%), carotid artery thickness (-30%), low-density lipoprotein cholesterol oxidation (-90%), and by enhancing myocardial blood flow (+17%) (Sumner et al., 2005) and antioxidant status (+130%), and promote inhibition of some cellular transcription factors such as the nuclear factor NF-κB, tumor necrosis factor α and cyclooxygenase-2, block their production and combat inflammatory degeneration of cartilage to protect articulations.

Furthermore, in a spectrophotometric comparative study between POMj, red wine, blueberry juice, cranberry juice, orange juice and green tea, POMj was found to have the highest capacity to destroy free radicals and to decrease LDL oxidation and impede cellular oxidative stress in macrophages, with an antioxidant activity three times higher than red wine and green tea (Azadzoi et al., 2015). The ability of POMj is mainly due to its high bioavailability compared to other polyphenols such as resveratrol.

The underlying mechanisms of the biological polyphenol benefits are not yet clear but it was clearly proved especially in people placed under stressful situations (Ammar et al., 2016) (Fig. 1).

**Oxidative Stress and Sport Performance**

Humans and other aerobic organisms constantly produce free radicals as part of normal metabolic processes. Free radicals are defined as molecules or molecular fragments with one or multiple unpaired electrons in the atomic or molecular orbital. Free radicals derived from oxygen are called reactive oxygen species (ROS) (Gutteridge & Halliwell, 2000).

They are physiologically produced in different cellular biochemical reactions occurring in the body, such as in mitochondria for ATP production, in fatty acid metabolism, in drug metabolism and during activity of the immune system. Although the free radicals have positive effects in cellular signaling and immune reactions, they are also known for the negative role, such as oxidative damage of proteins, lipids, and nucleic acids (Gutteridge & Halliwell, 2000).

Free radicals are constantly produced in several tissues (liver, kidneys, heart, skeletal muscle, etc.) at rest, inducing a level of oxidative damage in these tissues. ROSs are the main oxidizing agents in cellular systems, and are involved in aging and the onset of some types of syndromes (D’Angelo et al, 2012b; D’Angelo et al, 2013; Galletti et al, 2007; Sies, 2008).
On the other hand, free radicals can also be produced by exogenous factors such as pollution, UV rays, ionizing radiation, bad lifestyle habits, smoking, diet and psychophysical stress resulting from intense physical activity (Gutteridge & Halliwell, 2000). There is proving that ROS formation in response to vigorous physical exertion can produce oxidative stress. More recent studies have showed the important action of ROS as signaling molecules. ROS modulate contractile function in fatigued and un-fatigued skeletal muscle. Moreover, involvement of ROS in the modulation of gene expression via redox-sensitive transcription pathways represents a significant regulatory mechanism, which has been suggested to be implicated in the process of training adaptation.

The strenuous exercise acutely enhances oxidative stress biomarkers, accompanied by a prolonged pro-oxidant redox status following such exercise. Physical exercise exerts a body physiological stress, which requires a coordinated response from the nervous, cardiovascular, and pulmonary systems to increase blood flow and oxygen supply to the operating skeletal muscle. Athletes often face a reduction in immune function due to intense training and difficult competition, becoming more prone to infections of the upper respiratory tract.

In the last 40 years, the role of ROS in exercise physiology has received considerable attention. Paradoxically, besides many health benefits, intense exercise can induce cell oxidative damage. Acute physical exertion has been shown to induce an augmented generation of ROS in skeletal muscle via different mechanisms.

The skeletal muscle usually produces free radicals: ROS production increases during contractile activity. In fact, aerobic exercise augments oxygen consumption (especially by the contracting muscle) with an increase of 15-fold in the rate of whole body O$_2$ uptake and an increase of more than 100-fold in the O$_2$ flux in active muscles (Powers et al., 2016; Bailey et al., 2007).

During exercise, oxygen demand increases, particularly in skeletal muscle, causing a dramatic change in the blood flow to various organs. Exercise-induced muscle damage promotes infiltration of phagocytes (i.e., neutrophils and macrophages) at the site of injury: these physiological changes increase free radical production, leading to oxidative damage to biomolecules.

Organisms are equipped with antioxidant defense systems that protect cells from the toxic effects of free radicals. Antioxidant defense systems are divided into enzymatic, such as superoxide dismutase, catalase, and glutathione peroxidase, and non-enzymatic, such as vitamin C, vitamin E, glutathione, and bilirubin. The antioxidants play important action in delaying or preventing oxidation of intracellular and extracellular biomolecules. Oxidative stress reflects an imbalance between oxidant production and antioxidant responses where the former exceeds the latter Therefore, regular exercise leads to the up-regulation of the antioxidant defense mechanisms, in order to downplay the oxidative stress. During exercise, ROS production can be higher than the muscle antioxidant ability (Webb et al., 2017).

The capacity of antioxidant systems is affected by intake of nutrients, such as minerals and vitamins. Therefore, antioxidant supplementation can attenuate the deleterious impact of oxidative stress thus improving exercise performance. To date, the data from researches using antioxidants are equivocal as increases, no change, and decreases in performance have been reported (Kawamura & Muraoaka, 2018).

Foods and supplements high in polyphenols are gaining popularity within sports nutrition. They have anti-inflammatory and anti-oxidative activities that improve recovery from exercise. Furthermore, polyphenols can also influence vasoactive capabilities, including decreasing mean arterial blood pressure and increasing vasodilation during exercise (Malaguti et al., 2013). In vitro observations have shown polyphenol- and metabolite-induced activation of endothelial nitric oxide synthase and human vascular cell migration.

In sport, polyphenols exert physiological effects that can increase by 1.90% a diversity of athletic performance parameters, such as exercise time to fatigue, distance covered in a pre-selected time period, time to complete a certain distance and maximum power output. Moreover, there are a number of reviews supporting the role of polyphenol supplementation in endurance performance showing decreased rate of perceived exertion, increased maximal oxygen uptake and a faster recovery of muscle capacity (with a parallel trend to a faster decrease of inflammatory markers (Harty et al., 2019). The mechanisms by which polyphenols intake can enhance exercise performance may include effects on blood flow, metabolic pathways, and peripheral muscle fatigue, or a combination of all three. However, actions of polyphenols on exercise performance without a prior muscle-damaging or metabolically demanding about of exercise are less clear (Sellami et al., 2018). For example, exercise performance effects have been observed for blackcurrant but are less apparent for cherry, therefore indicating that the benefits could be due to the specific source-dependent polyphenols. (Myburgh, 2014; D’Angelo, 2019a).

Pomegranate juice is a rich source of polyphenols, such as anthocyanins, flavanols and some ellagitannins, especially punicalagin. Many studies have documented the beneficial effects of POM consumption in the treatment of various disorders. Researchers have recently become increasingly interested in the dietary supplementation of athletes with POM.
POM exerted a positive effect on the modulation of fat and protein damage in well-trained endurance-based athletes (Fuster-Muñoz et al., 2016). The consumption of POM, 48 h prior to, and during training sessions contributed to the alleviation of pain, delayed damage, inflammation, and soreness of the knee flexor, accelerated the recovery kinetics of biological parameters and improved performance in nine elite weightlifters. (Ammar et al., 2016). In this context, this document summarized experimental evidence of the role of pomegranate in improving exercise performance in humans.

**Literature Search Strategy**

In this article, a bibliographic review was carried out using the PubMed and Web of Science databases. They have been analyzed the most relevant articles and studies made in human subjects published no longer than approximately ten years ago and reviewed in the English language literature. The keywords used for this search were: pomegranate, phytochemicals, nutraceuticals, sport performance, oxidative stress, and inflammation. The exclusion criteria consisted in interventional studies published before 2010; interventions made in animals.

**Results and discussion**

Many studies have documented the beneficial effects of POM consumption in the treatment of various disorders (Faria et al, 2007; Shema-Didi et al, 2012). Researchers have recently become increasingly interested in the dietary supplementation of athletes with Pomegranate juice (POM). (Table 1). 1 g of pomegranate extract, consumed 30 min prior to exercise enhanced time to exhaustion while running at 90% and 100% of peak velocity achieved at VO2max, by ~12% and ~8%, respectively (Trexler et al., 2014). Acute ingestion of POM 30 min prior to exercise may enhance vessel diameter, blood flow, and delay fatigue during exercise. Results of the current study indicate that POM is ergogenic for intermittent running, eliciting beneficial effects on blood flow (Trexler et al., 2014).

A combined supplement of pomegranate, green tea, and grape extract (×2500 mg capsules = 290 mg polyphenolic bioactive) consumed acutely 1 h pre-exercise increased total power output (5%), maximal peak power output (4%), and average power output (5%) during repeated cycle Wingate tests in recreationally active individuals (Cases et al., 2017), without inducing a higher fatigue index in supplement versus placebo treatments or greater post exercise heart rate. Such results demonstrated that POM is a natural and efficient solution capable of, similarly to training benefits, helping athletes to improve their physical performance, while balancing their metabolism and reducing exercise-induced oxidative stress (Cases et al., 2017) (Table 1). Furthermore, trained cyclists acute POM supplementation allowed a partial restoration of VO2 during intense exercise in a hypoxic environment. Although acute POM supplementation was associated with a 10.3 μmol increase in plasma NO3−, its use as an acutely-ingested ergogenic supplement by highly-trained athletes is not supported by the study, as neither performance nor submaximal VO2 were significantly altered by POM ingestion. However, data indicated that POM does allow maintenance of VO2 at a workload prescribed to elicit 100% VO2max during high intensity exercise under low PO2 conditions, despite no significant performance effect (Crum et al, 2017). Roelofs et al., have observed that acute supplementation of POM resulted in enhanced vessel diameter, blood flow, and peak and average power output in individuals submitted to repeated sprint ability and repetitions to fatigue. These improvements are likely due to the nitrate and polyphenol content in pomegranate extract, which have likely resulted in increased nitric oxide to enhance endothelial function and enhance exercise performance. The study demonstrated POM to be effective when ingested 30 minutes before exercise. The acute timing and the method of administration of POM may be advantageous to the athletic population due to ergogenic effects, taste, compliance, convenience, and POM being a natural compound. Power output and repetitions were increased after POM ingestion suggesting a potential for increasing training volume. Additionally, combining POM with other ergogenic aids may be advantageous as a pre-workout supplement to further augment performance (Roelofs et al., 2017) (Table 1).

Consuming POMj supplementation, 9 elites athletes, during weightlifting training session and during the 48h before, reduces the acuteness of the pain and delayed responses of the muscle damage and inflammation, and muscle soreness (i.e., knee flexor); it accelerates the recovery kinetic of the biological parameters and improve the weightlifting performance. Therefore, elite weightlifters might benefit from blunted oxidative stress responses following intensive weightlifting sessions, which could have implications for recovery between training sessions. However, given the small sample size, further studies should verify these results using greater sample of athletes (Ammar et al., 2016; Ammar et al., 2017). Fuster-Muñoz et al, demonstrated that POM exerted a positive effect on the modulation of fat and protein damage in well-trained endurance-based athletes (Fuster-Muñoz et al., 2016). The effect of pomegranate juice supplementation on the levels of selected pro-inflammatory cytokines, hepcidin and markers of iron metabolism has been studied in well-trained rowers. During the resting period, the total antioxidant ability level in the supplemented group was significantly higher than in the placebo group. The ergometric test conducted at baseline demonstrated a significant post-exercise increase in the concentrations of soluble transfer in receptors, iron and serum interleukin 6. Supplementation with POM contributed to an important strengthening of plasma antioxidant potential in the group of well-trained rowers, but had no significant effect on inflammatory markers or other parameters analyzed (Urbania et al., 2018).
Table 1. Summary of studies examining the effect of pomegranate on exercise performance.

<table>
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<th>References</th>
<th>Participants</th>
<th>Intervention</th>
<th>Exercise protocol</th>
<th>Outcomes measured</th>
<th>Performance improvements reported</th>
<th>Original conclusion</th>
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<tr>
<td>D’Angelo, S., et al.: The impact of supplementation with pomegranate...</td>
<td>19 highly active participants</td>
<td>1 g of pomegranate extract, 30 min prior to exercise</td>
<td>Two sets of three treadmill runs</td>
<td>Blood flow, vessel diameter</td>
<td>Enhanced vessel diameter, blood flow, delay fatigue during exercise.</td>
<td>Ergogenic for intermittent running</td>
</tr>
<tr>
<td>Fuster-Múñoz et al., 2016</td>
<td>31 athletes</td>
<td>200 mL/d pomegranate juice</td>
<td>Endurance-based exercises</td>
<td>Plasma oxidative stress markers (protein carbonyls and malondialdehyde)</td>
<td>Improved malondialdehyde levels and carbonyls, decreased the oxidative damage</td>
<td>Other studies are needed</td>
</tr>
<tr>
<td>Roeilofs et al., 2017</td>
<td>21 recreationally-active participants</td>
<td>1000 mg consumed 30 min prior to test and repetitions to fatigue on bench and leg press.</td>
<td>Brachial artery blood flow and vessel diameter</td>
<td>Enhanced vessel diameter, blood flow</td>
<td></td>
<td>Ergogenic effects</td>
</tr>
<tr>
<td>Ammar et al., 2014</td>
<td>9 elite weightlifters</td>
<td>500 ml of POM daily for two months</td>
<td>Two Olympic weightlifting sessions</td>
<td>Heart rate, blood pressure and blood samples</td>
<td>Attenuated oxidative stress, enhanced antioxidant responses</td>
<td>Accelerated muscle recovery</td>
</tr>
<tr>
<td>Cases et al., 2014</td>
<td>15 recreationally-active male athletes</td>
<td>1000 mg of the POM supplement</td>
<td>4 × 30s bouts of cycling at all-out intensity</td>
<td>Blood pulse pressure, erythrocytes, antioxidant enzymes, LDH.</td>
<td>Significant increase in total power output, in maximum peak power output; oxidative homeostasis stabilized</td>
<td>Athletes helped to improve performance</td>
</tr>
<tr>
<td>Crum et al., 2017</td>
<td>8 cyclists</td>
<td>Pre-exercise consumption of 1000 mg of POM</td>
<td>Cycling time trial to exhaustion at 100%VO2max</td>
<td>Heart rate, plasma nitric acid,VO2</td>
<td>An increase in VO2, no change in exercise performance occurred</td>
<td>POM not an ergogenic supplement</td>
</tr>
<tr>
<td>Urbaniak et al., 2018</td>
<td>19 male well-trained rowers</td>
<td>50 ml of POM daily for two months</td>
<td>A controlled 2000-m rowing exercise test</td>
<td>Plasma antioxidant capacity, interleukin 6, uric acid, hepcidin, soluble transferrin receptor</td>
<td>Boosted total antioxidant capacity, no significant effect on inflammatory markers</td>
<td>----</td>
</tr>
<tr>
<td>Torregrosa-Garcia et al., 2019</td>
<td>26 amateur cyclists</td>
<td>225 mg punicalagins/day, for 15 days</td>
<td>Endurance bouts, eccentric exercises drill.</td>
<td>Total time to exhaustion, oxygen consumption and maximum oxygen consumption, constant intensity endurance test, rate of perceived exertion</td>
<td>Greater values in total time to exhaustion, No results for force restitution in the isokinetic unilateral low limb test</td>
<td>A help to restore force in the damaged muscles</td>
</tr>
<tr>
<td>Trombold et al., 2010.</td>
<td>16 recreationally active males</td>
<td>Pomegranate juice 800 mL/day for 9 days</td>
<td>Two sets of 20 maximal eccentric elbow flexion exercises with one arm</td>
<td>Maximal isometric elbow flexion strength, muscle soreness, serum markers</td>
<td>Improves recovery of isometric strength 2-3 after a damaging eccentric exercise.</td>
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<tr>
<td>Trombold et al., 2011.</td>
<td>16 recreationally active males</td>
<td>Pomegranate juice 500 mL/day for 15 days</td>
<td>3 sets of 20 unilateral eccentric elbow flexion and 6 sets of 10 unilateral eccentric knee extension exercises.</td>
<td>Elbow flexion strength, elbow flexor muscle soreness, isometric strength and muscle soreness in the knee extensors.</td>
<td>Attenuates weakness and reduces soreness of the elbow flexor, but not of knee extensor muscles.</td>
<td>Acute ergogenic effect in the elbow flexor muscles of resistance trained individuals after eccentric exercise.</td>
</tr>
<tr>
<td>Machin et al., 2014</td>
<td>45 nonresistance trained, recreationally active men</td>
<td>30-60 mL/day servings of POM</td>
<td>20 min of downhill running and 40 maximal eccentric elbow flexion repetitions</td>
<td>Isometric knee extensor and elbow flexor strength, muscular soreness, and serum myoglobin</td>
<td>Improves strength recovery in leg and arm muscles following eccentric exercise; no dose response</td>
<td>No difference between once daily or twice daily supplementation on strength recovery after eccentric exercise.</td>
</tr>
<tr>
<td>Lamb et al., 2019</td>
<td>36 non-resistance trained men</td>
<td>2 × 250 mL of POM twice daily for nine days</td>
<td>Eccentric exercise of the elbow flexors of their non-dominant arm</td>
<td>Maximal isometric voluntary contraction, delayed onset muscle soreness, creatine kinase, range of motion</td>
<td>No significant differences in treatment group</td>
<td>In non-resistance trained men no enhance recovery from high-force eccentric exercise of the elbow flexors.</td>
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</table>

Trombold and colleagues found that recreationally active males who consumed pomegranate juice (800 mL/day for 9 days) retained significantly greater muscle function following damaging eccentric exercise (2 × 20, MVC) on day 5 of supplementation compared to those who consumed an isocaloric placebo (Trombold et al, 2010). These effects were replicated by the same research group (Trombold et al, 2010) using resistance-trained males who consumed pomegranate juice (500 mL/day) for 15 days. On the eighth day, the subjects performed 3 × 20 maximal eccentric elbow extensions and 6 × 10 maximal eccentric knee extensions.  

Summary of studies examining the effect of pomegranate on exercise performance.

Participants: 19 highly active participants; 31 athletes; 21 recreationally-active participants; 9 elite weightlifters; 15 recreationally-active male athletes; 8 cyclists; 19 male well-trained rowers; 26 amateur cyclists; 16 recreationally active males; 16 recreationally active males; 45 nonresistance trained, recreationally active men; 36 non-resistance trained men.

Intervention: 1 g of pomegranate extract, 30 min prior to exercise; 200 mL/d pomegranate juice; 1000 mg consumed 30 min prior to test and repetitions to fatigue on bench and leg press; 500 ml of POM daily for two months; 1000 mg of the POM supplement; Pre-exercise consumption of 1000 mg of POM; 50 ml of POM daily for two months; 225 mg punicalagins/day, for 15 days; Pomegranate juice 800 mL/day for 9 days; Pomegranate juice 500 mL/day for 15 days; 30-60 mL/day servings of POM; 2 × 250 mL of POM twice daily for nine days.

Exercise protocol: Two sets of three treadmill runs; Endurance-based exercises; Repeated sprint ability test and repetitions to fatigue on bench and leg press; Two Olympic weightlifting sessions; 4 × 30s bouts of cycling at all-out intensity; Cycling time trial to exhaustion at 100%VO2max; A controlled 2000-m rowing exercise test; Endurance bouts, eccentric exercises drill; Two sets of 20 maximal eccentric elbow flexion exercises with one arm; 3 sets of 20 unilateral eccentric elbow flexion and 6 sets of 10 unilateral eccentric knee extension exercises; 20 min of downhill running and 40 maximal eccentric elbow flexion repetitions; Eccentric exercise of the elbow flexors of their non-dominant arm.

Outcomes measured: Blood flow, vessel diameter; Plasma oxidative stress markers (protein carbonyls and malondialdehyde); Brachial artery blood flow and vessel diameter; Heart rate, blood pressure and blood samples; Blood pulse pressure, erythrocytes, antioxidant enzymes, LDH; Total time to exhaustion, oxygen consumption and maximum oxygen consumption, constant intensity endurance test, rate of perceived exertion; Plasma antioxidant capacity, interleukin 6, uric acid, hepcidin, soluble transferrin receptor; Maximal isometric elbow flexion strength, muscle soreness, serum markers; Elbow flexion strength, elbow flexor muscle soreness, isometric strength and muscle soreness in the knee extensors.

Performance improvements reported: Enhanced vessel diameter, blood flow, delay fatigue during exercise. Improved malondialdehyde levels and carbonyls, decreased the oxidative damage. Significant increase in total power output, in maximum peak power output; oxidative homeostasis stabilized. Significant increase in VO2, no change in exercise performance occurred. Boosted total antioxidant capacity. Greater values in total time to exhaustion. A help to restore force in the damaged muscles. Improves recovery of isometric strength 2-3 after a damaging eccentric exercise. Attenuates weakness and reduces soreness of the elbow flexor, but not of knee extensor muscles. Improves recovery. Improves strength recovery in leg and arm muscles following eccentric exercise; no dose response. No significant differences in treatment group.

Original conclusion: Ergogenic for intermittent running. Other studies are needed. Accelerated muscle recovery. Athletes helped to improve performance.
Post-exercise measures of upper body but not lower body strength were preserved and soreness decreased relative to placebo during the entire 7 days of recovery in the treatment group (Table 1). The researchers theorized that minor differences in the exercise stimulus applied to the elbow flexors and knee extensors or the relatively greater action of the knee extensors during activities of daily living may have contributed to this pattern. A third investigation conducted by the group (Machin et al., 2014) found that once-daily consumption of 30 mL pomegranate juice concentrate had similar efficacy relative to twice-daily consumption (60 mL/day) in recreationally active men. After 3 days of supplementation, the subjects performed a 20-min bout of downhill running and 40 eccentric elbow contractions at 100%. During the 4-day recovery phase, the researchers noted that both treatment groups displayed higher knee extension and elbow flexion maximal voluntary contraction relative to placebo (Machin et al., 2014).

In thirty-six non-resistance trained men, the intake of 2 × 250 mL of POM doesn’t improve delayed onset muscle soreness and other markers. These results suggest that in non-resistance trained men, POM does not enhance recovery from high-force eccentric exercise of the elbow flexors (Lamb et al., 2019). In a study on 26 amateur cyclist, the efficacy of POM have been evaluated in performance outcomes and post-exercise muscular recovery and force restoration after a prolonged submaximal effort have been evaluated. No significant results were found for force restoration in the isokinetic unilateral low limb test. POM, after a prolonged submaximal effort, may be effective in improving performance outcomes at maximal effort and might help to restore force in the damaged muscles (Torregrosa-Garcia et al., 2019) (Table 1).

Conclusion

Exercise-induced muscle damage typically results in impaired performance, increased pain and soreness, and reduced training quality. Athletes and active individuals who require rapid recovery between bouts of damaging exercise/physical activity should implement well-supported nutritional and supplementation strategies to augment and assist with the recovery process. A wide assortment of nutritional and supplementation strategies have been investigated by researchers, with varying results. Initial evidence suggests that the long-term consumption of antioxidant-rich foods (tart cherry juice, pomegranate juice, beetroot juice, and watermelon juice) as well as several supplementation strategies (ω-3 polyunsaturated fatty acids, and vitamin D₃) may help to reduce symptoms of exercise-induced muscle damage and improve muscle function in a variety of populations.

Polyphenols have been purported to improve aerobic metabolism through stimulation of mitochondrial biogenesis (by increasing expression of genes encoding cytoprotective proteins and activation of sirtuins, mediated by specific polyphenols such as catechins, resveratrol, quercetin and curcumin). On the other hand, antioxidant supplementation may impair muscle performance by decreasing force production (by blocking oxygen delivery from blood to myocytes and by modifying basal cellular redox state) and training adaptations derived from physical stress. Food supplements made of natural extracts can have a multifactorial effect, due to a rich variety of active substances (such as different types of polyphenols, depending on the source), so specific mechanisms underlying their ergogenic effect are not easily deciphered. On the contrary, isolated active substances or standardized raw materials allow a more specific metabolic target but may hamper average supplement’s effect size by synergistic substances naturally present or by other unclear mechanisms. Future clinical trials on isolated active ingredients (such as punicalagins) would elucidate the specific metabolic and biochemical pathways taking place, which will be of great value for subsequent future research lines regarding exercise performance and health.

References


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