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Polyphenolic-rich Fruits and Supplements Enhance Exercise Performance; General Review

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ABSTRACT

Background: It has been widely accepted that regular exercise represents an important factor to improve health; for the magnificent benefits you can get on the short term and long term. To pave the way for better performance in exercise by improving body strength and reducing risks of muscle injuries, intake of proper nutrients is vital. There are many types of nutrients found in our diets that are all necessary, yet some have additional values. Polyphenols are not only considered for their bioavailability profile, but for their antioxidant properties as well as their diverse beneficial actions.

Aims and objectives: The intent of this review is to provide prevalent information on the effect of polyphenol-rich fruits and polyphenols supplements from different sources on exercise performance. Performance is usually modeled by strength, endurance, and recovery. The role of oxidative stress and free radicals in exercise performance will also be highlighted. Oxidative stress has been associated with decreased physical performance, muscular fatigue and muscle damage. Antioxidants supplementation of the diet may be one intervention to reduce exercise-induced oxidative stress in athletes.

Conclusions: It has been demonstrated by several studies presented in this review that polyphenols have been shown to reduce oxidative stress biomarkers, increasing blood flow, increasing O_2 gas supply, reducing muscle damage, and therefore improving recovery, endurance, and strength in physically active individuals.

Keywords: Exercise performance; Endurance; Polyphenols; Berries; Pomegranate; Oxidative stress; Free radicals.

1. INTRODUCTION

Physical exercise, physical activity and nutritional behaviour are now well considered to be essential components of a healthy lifestyle. Whether it's moderate or exhaustive type of exercise; they both involve muscle contractions and an increase in by-products and free radicals. Moderate and regular exercise have been shown to be useful in the prevention of cardiovascular disease, metabolic syndrome, type II diabetes, and neurodegenerative disease like Alzheimer's and Parkinson's disease[1]. Moreover, this type of exercise maintains body fitness, body health and overall enhancement of well being[2]. Protection against stressors and adaptation responses might develop with moderate regular exercising, which in turns plays a key role in the prevention of chronic and degenerative diseases[1].

Numerous studies have demonstrated the ability of exercise training to stimulate positive adaptations in skeletal muscles in adults of all ages. This includes increased muscle strength, increased protein synthesis, increased muscle mass, changes in myosin heavy-chain composition, and increased proportion of satellite cells that are precursors to skeletal muscle cells[2]. Individuals who participate in regular exercise and physical activity have profoundly lower rates of disability and an average life expectancy approximately seven years longer than sedentary individuals. As regular exercise maintains a

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delicate balance between ROS and NO that keep a healthy cardiovascular system, however, too much exercise is detrimental and disturbs this balance. On the other hand, sedentary life style induces vascular dysfunction[3].

Some moderate exercisers progress to a further level and become athletic and perform exhaustive exercise including powerful cycling, swimming, running for long durations and long distances as well as to cross training and body muscle building. Beside the superior benefits these athletes are experiencing the increased intensity may produce additional stress on their muscles[3,4]. Consuming functional and nutritive food containing antioxidants would be inevitable when a healthy lifestyle and exercise were followed. Diet that rich in antioxidants (substances which remove free radicals by neutralizing them as a result of metabolic reactions) would be essential to enhance performance during exercise[5,14,50,52]. Plant polyphenols are the most abundant antioxidants in diet.

The aim of this review is to study the effect of natural fruits and products rich in antioxidants on the 3 main aspects of exercise performance; Endurance, strength and recovery. In addition, how each one of these is enhanced by polyphenolic compounds, whether during different types of workouts a person may do or regular exercise and also the various polyphenolic fruits and sources.

Methods

The preparation of this general review followed several steps**:** Identification of research question of how polyphenolic rich products enhance exercise performance, literature survey of relevant studies and eligible ones were selected based on inclusion and exclusion criteria and then organising the research according to 3 main exercise activities; endurance, strength and recovery. This review excluded non relevant studies whose participants were smokers, on medications, physically handy-caped individuals, and children. Full texts were verified against the inclusion criteria whereby all young and adult females and males, both healthy or with mild chronic diseases were included. Also those non-smokers, physically active and inactive individuals were included. Relevant data were extracted and evaluated and this was made possible by searching different search engines primarily PubMed using relevant keywords.

Polyphenols Sources

Polyphenols are either synthetic or natural, and the latter are the most bioactive compounds. Natural polyphenols have been found in tea, cereals, medical plants, microalgae, and edible and wild flowers. High content of polyphenols was found in grape, pomegranate, olive, blueberry and other berries, sweetsop, mango and citrus fruits. The highest phenolic contents were found in Chinese toon bud, loosestrife, penile leaf, cowpea, caraway, lotus root, sweet potato leaf, soy bean (green), pepper leaf, ginseng leaf, chives, and broccoli. In addition, the pigmented cereals, such as black rice, red rice and purple rice, contained high total phenolic contents. *Salvia miltiorrhiza* Bge. (danshen), *Polygonum multiflorum* Thunb. (stem) (flowery knotweed), *Rhodiola sacra* Fu (hongjingtian), *Fraxinus rhynchophylla* Hance (ash), and *Prunus persica* (Linn) Batsch. (peach) showed high contents of natural polyphenols among medical plants. *Rosa rugosa* (rose), *Limonium sinuatum* (myosotis), *Pelargonium hortorum* (geranium), *Jatropha integerrima* (peregrina) and *Osmanthus fragrans* (osmanthe) were found to have lots of natural polyphenols among edible and wild flowers[6].

Chemical classes of Polyphenols: Chemically, polyphenols are usually composed of sugar residues linked directly or indirectly to hydroxyl groups of the phenolic compounds. It is common to find linkage with other compounds, such as carboxylic and organic acids, amines, lipids and association with other phenols. The number of phenol rings is also used to subdivide polyphenols into different groups. Several sub-classes, such as the phenolic acids, flavonoids, stilbenes and lignans are shown in figure 1 below[5,6]. Polyphenols interact with important cellular signal cascades including NFκB, MAPK and PI3K/Akt; that are found to reduce adverse processes in inflammation and atherogenesis[11].

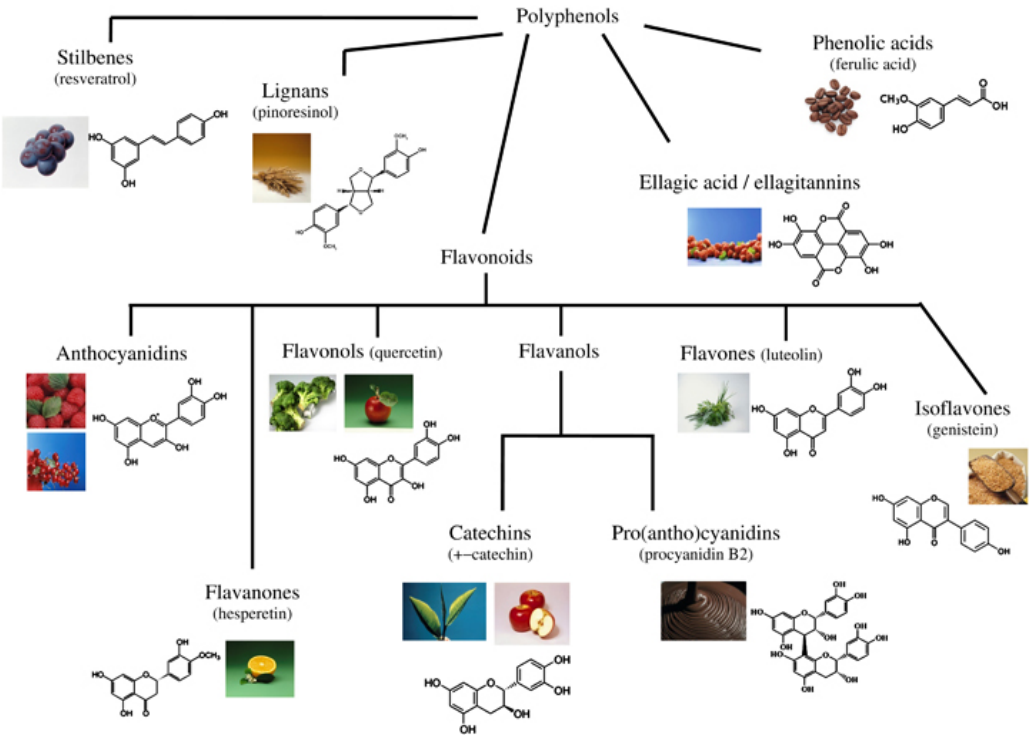

Figure 1. Chemical classes and subclasses of polyphenols[49]

Pomegranate: The majority of studies have used pomegranate, or **Punica granatum**; is a shrub that produces a red fruit, categorized as a berry. The skin of the pomegranate is thick and inedible, but there are hundreds of edible seeds called arils inside. The arils are what we eat, either raw or processed into pomegranate juice. Pomegranates contain Punicalagins which are extremely powerful antioxidants and anti-inflammatory, found in the juice and the peel. Pomegranates are studied relatively more than any other fruit[7]. In a spectrophotometric analysis, comparison between pomegranate juice, red wine, blueberry juice, cranberry juice, orange juice and green tea, it was found that pomegranate juice products have the highest antioxidant capacity to neutralize free radicals and to reduce LDL oxidation and inhibit cellular oxidative stress in macrophages, with an antioxidant activity three times higher than red wine and green tea[8]. The significance of pomegranate juice is mainly due to its relative high bioavailability compared to other polyphenols such as resveratrol[9] which makes it very useful for medicinal purposes.

Pomegranate fruit parts: Knowing which part of the pomegranate contains the highest or lowest content of polyphenolic compounds is an important issue to consider when performing research studies. One of the studies was done in 2011 on the juice, peel, and seed extracts of four Turkish pomegranates, **Punica granatum** L. cultivars. Interestingly, in all cultivars, the highest levels of total phenolic content were obtained from the peel extracts. The total phenolic content range was (1775.4 to 3547.8 mg gallic acid equivalent GAE/L) among the cultivars. However, the total phenolic content of pomegranate juice and seed extract range was 784.4 to 1551.5 mg GAE/L and 117.0 to 177.4 mg GAE/L respectively. Among the 4 popular cultivars tested, "Lefan" cultivar displayed the highest amount of the total phenolic content[10].

Extraction of polyphenols: Efficient methods to safely extract polyphenols using eco-friendly and cost efficient

methods are available. While mechanisms of the so called green extractions vary between modern green extraction techniques such as supercritical fluid extraction, microwave-assisted extraction, ultrasound-assisted extraction, pressurized liquid extraction, and pressurized hot water extraction are alternatives to conventional extraction methods for polyphenol extraction from natural sources. The green methods offer some advantages over the conventional methods, are more sustainable, fast, convenient, and eco-friendly[12].

Exercise Performance

Exercise performance is a multi-organ activity where oxygen availability is a major contributor. In recent years, it became well known that nitrate and polyphenols increase exercise efficiency and therefore, pomegranate extract is primarily investigated to study effect on blood flow, vessel diameter, and exercise performance in active individual[13].

***Reactive Oxygen species* (ROS)**: ROS causes tissue damage by releasing free radicals. In a study published in 2013 investigating the correlation between antioxidants and exercise performance, pomegranate polyphenols were chosen among other polyphenols in green tea and dark chocolate.[2] Another study published by Al-Dujaili and co-workers[14] concluded that intake of pomegranate juice attenuates exercise-induced oxidative stress, blood pressure and urinary cortisol/cortisone ratio in human adults where participants consumed either pomegranate pure juice (500 mL/day containing total polyphenols of 1685 mg GAE/L) or placebo (water matched for total energy) and all participants completed two 30 min treadmill tests (50% *W*max) at baseline and after one week of the intervention. As expected, PJ has alleviated ROS that was induced by moderate to extraneous exercise and reduced blood systolic and diastolic blood pressure possibly due to the counter affect of enzymatic antioxidants defence mechanism and 11β-HSD enzymes that modulate the conversion of cortisol to cortisone[14].

When trained runners subjected to exhaustive exercise, it was suggested that considerable increase of ROS levels was observed and that variations in oxygen consumed can underestimate the real increase in free radical formation during intensive exercise, as a result of the reduction of mitochondrial control of cell respiration and the increase in the formation of free radicals derived from non-mitochondrial sources. It was also observed in a football trained group an increase in plasma levels of low molecular weight endogenous antioxidants (ascorbic acid, uric acid, and α-tocopherol) compared to sedentary subjects. This increase was attributed to mobilization of the antioxidants from the tissues to the plasma, explaining the improvement of the total plasma antioxidant status after training[15]. In another study published in 2015[50] on the effect of dark grape juice consumption on exercise-induced oxidative stress in healthy adults aged 41 to 60 Years, the individuals aged 41 to 60 years old who exercised regularly and consumed dark grape juice have significantly increased the total phenolic and FRAP urinary levels and caused a significant decrease in one oxidative stress marker (TBARS). However, for the aged matched non-exercisers, there was an increase in total phenolics but did not appear to have a significant effect on oxidative stress markers[50].

VO_2 max: Higher intensity exercise was reported to produce optimal cardio vascular health. To investigate the optimal intensity needed to reach this phenomenon, young men were assigned to mild (25% VO_2 max), medium (50% VO_2 max) or high intensity (75% VO_2 max) exercise regimens for 12 weeks. Both endothelium dependent and independent vasodilation and markers of oxidative stress were examined. The medium intensity exercise group showed increased acetylcholine-mediated vasodilation in the forearm microcirculation while no benefit was observed in the mild and high intensity groups[4]. There has been a correlation between the high activity of antioxidant enzymes and the maximum oxygen consumed. Training athletes have a higher superoxide-dismutase (SOD) and catalyase (CAT) activity in skeletal muscles. Professional and amateur cyclists have higher SOD activity in erythrocytes than sedentary subjects. Due to this, resistance training reduces oxidative damage due to the

increased mitochondrial antioxidant enzymes and a reduction of the oxygen flow in the respiratory chain[15].

To study the role played by antioxidants in increasing blood flow to leg muscles and O_2 consumption with chronic obstructive pulmonary disease (COPD**),** a cocktail of antioxidants was prepared for that purpose. The 16 patients with COPD and 16 healthy subjects performed sub-maximal single-leg knee extensor exercise. The participants had 2 split doses; the first dose consisted of 300 mg α-lipoic acid, 500 mg vitamin C, and 200 IU of vitamin E, and the second dose consisted of the same amounts of α-lipoic acid and vitamin C and 400 IU vitamin E. These parameters, LBF (Doppler ultrasound), mean arterial blood pressure, LVC (leg vascular conductance), arterial O_2 saturation, leg arterial-venous O_2 difference, and leg O_2 consumption were evaluated under control conditions and after AOC administration. Patients with COPD exhibited evidence of reduced antioxidant capacity relative to healthy subjects. Administration of the AOC improved the redox balance in patients with COPD, with little effect in healthy subjects. These favourable changes in redox balance were accompanied by improved LBF and LVC as well as increased skeletal muscle $\dot{V}O_2$ during sub-maximal KE exercise in patients with COPD, whereas minimal effects were observed in healthy subjects. In addition, arterial O_2 saturation was improved at rest and during exercise in patients with COPD after AOC administration[16]. Muscle damage, muscle dysfunction, and worn-out tendons and joints may result from exhaustive exercise. High impact muscle contraction causes an increase in the production of matrix metalloprotienase (MMPs) in the skeletal muscles. MMPs are a family of enzymes, zinc-dependant that plays a role in mediating inflammation, remodelling and regeneration of skeletal muscles[5].

Pomegranate and Anaerobic Exercise: Exercise performance could be accomplished by multiple factors and the availability of oxygen gas partial pressure contributes to a great deal. When the body depletes the amount of oxygen gas available, it seeks refuge to anaerobic. Therefore, some studies investigated how PE supplementation affect anaerobic exercise and flow mediated dilation (FMD), oxygen saturation, heart rate (HR), and blood pressure (BP). Nineteen participants ingested 1000mg of PE or PL performed ten six-second maximal sprints with a load of 65 g/kg of body weight and 30 seconds of recovery in between rounds. Ergometer was used to assess peak and average power. Ultrasound measured brachial artery, vascular, pulse wave, and color flow to determine blood flow and vessel diameter[16]. It was found that peak power was significantly higher for the 5th sprint number when supplemented with PE versus PL. Vessel diameter was significantly greater at 30min post-exercise and blood flow was significantly higher immediately post exercise when PE was consumed. There were no significant differences identified in oxygen saturation, heart rate, or blood pressure. Results suggest the possibility of enhanced exercise performance due to increased diameter of vessels which caused better delivery of oxygen and substrates to working skeletal muscle with the use of PE[16].

The effect of grape seeds and cranberry polyphenols consumption on anaerobic cycling performance and brachial artery flow-mediated dilation (FMD) was studied in 2 parts of a study involved elite athletes in Canada[19]. In the first part of the study, 8 males and females elite athletes consumed either polyphenols from cranberries and grape seeds (600 mg) or a polyphenol-free placebo drink. Those who consumed the polyphenol-rich drink had a significant rise in FMD compared to placebo with a peak at 60 min[19]. In the second part, 12 elite male and female athletes completed a 3-km time trial (TT) on an ergocycle on two occasions in random order, either after consumption of 800 mg of polyphenols or a placebo. The study showed that acute intake of the polyphenol extract had no impact on the three-kilometer time trial but improved endothelial function. However, plasma lactate levels were significantly lower before and after the TT when subjects consumed the polyphenols *vs.* placebo. Acute modification of FMD at rest is suggested by intake of polyphenols from cranberries and grape seeds, but this did not translate into

enhanced cycling anaerobic performance[17].

Pomegranate and Aerobic Exercise: *A*erobic training was suggested to improve the enzymatic antioxidant activity in erythrocytes in basal state and in the recovery period after exercise, along with the increase of muscle blood flow and the mitochondrial aldehyde dehydrogenase activity. This improvement could be responsible for the significant decrease of lipid peroxidation index after exercise in trained subjects. A study was done to explore the antioxidant status of highly trained runners (128–230 km/week), moderate and low trained runner (26–70 km/week), and sedentary subjects.[38] The results showed a direct relationship between the weekly distance achieved and the erythrocyte antioxidant enzymes activity. It was found that trained marathon runners have higher levels of Malondialdehyde (MDA) and conjugated dienes (CD) in basal state than sedentary subjects. At the end of the half marathon, trained subjects showed a significant increase in the MDA and CD levels, however test values decreased in the recuperation period (24–48 hours) to lower values. In another study, Erythrocyte catalase activity and glutathione reductase were shown to increase significantly after 10 weeks of training[15].

A study was performed to assess the effect of pomegranate on aerobic exercise measuring blood flow, time to exhaustion, and vessel diameter.[13] Participants performed a maximal oxygen consumption treadmill test to determine peak velocity (PV), returned after 24–48 h and ingested either PL or PE. Three treadmill runs to exhaustion were performed at 90%, 100%, and 110% PV. Blood flow was assessed immediately after each exercise round and 30 min post-exercise (30min PEx). Compared to PL, acute ingestion of PE (30 min before exercise) seems to enhance vessel diameter and blood flow and delay fatigue during exercise. The results indicated that PE is an ergogenic for intermittent running, eliciting beneficial effects on blood flow which is an important factor of aerobic exercise[13].

Studies on Endurance or stamina, Strength Exercise and Recovery

Endurance Exercise

The capacity to remain active for a long period of time, and withstand the physical stress, wear and tear before becoming fatigued is referred to as stamina or endurance. Fatiguing caused by accumulation of by-products of metabolic pathways like magnesium, urea nitrogen, creatine kinase, lactate, and reactive oxygen species (ROS). Repetitive high intensity workout may overwhelm the body systems and prevents detoxification[18].

ROS/Oxidative stress: The role of Glutathione as an antioxidant has been studied lately to a greater extent. Some Endurance exercise studies have shown decreased level of Glutathione but increased level of oxidized Glutathione due to the oxidative stress exercise might have caused. An increase in Glutathione reductase enzyme level in serum has also been observed[20]. Oxidative stress has been associated with decreased physical performance, muscular fatigue, muscle damage, and overtraining. Human body naturally occurring antioxidants are not sufficient to neutralize high ROS levels; additional antioxidants are necessary. However, not all studies have shown the association between antioxidants and ROS in reducing fatigue, muscle damage, and increased performance following antioxidants intake[21].

In 2013, a study was done using extra virgin olive oil in rats. The rats were divided into three groups: (1) rats fed with standard chow and not subjected to physical exercise; (2) rats fed with standard chow and subjected to exhaustive exercise; (3) rats fed with a diet rich in oleic acid, the major component of extra-virgin olive oil, and subjected to exhaustive exercise (running in a five-lane 10◦ inclined treadmill at a speed of 30 m/min for 70–75 min). Oxidative stress biomarkers were studied and antioxidant defences, as well as histology and ultra-structure of the Quadriceps femoris muscle (Rectus femoris). The results showed that in group 3 rats, parameters indicating oxidative stress such as hydroperoxides and thiobarbituric acid-reactive

substances decreased, parameters indicating antioxidant defences of the body such as non-enzymatic antioxidant capacity and Hsp70 expression increased, and R. femoris muscle did not show histological and ultra-structural alterations. Results of this study support the hypothesis that extra-virgin oil can improve the body defence against oxidative stress[22].

Nitric Oxide: Endurance is made possible only if the demand for elevated oxygen and energy substrates in active skeletal muscle is met. To meet this high demand, blood flow to working musculature is increased in a process known as exercise hyperemia which affects blood flow and nitric oxide (NO) and has been identified as a vital contributor to the vasodilation observed after exercise[13]**.** NO production includes a series of reactions oxidizing L-arginine(a precursor) to L-citrulline and NO. These reactions are catalyzed by NOS enzymes, and require the presence of oxygen and L-arginine. In fact, a number of studies have investigated the effects of arginine and citrulline-based supplements on exercise performance. This has led to speculation that L-citrulline-based supplements may improve performance more effectively than L-arginine, however, more research is needed to evaluate the effects of L-citrulline supplementation on blood flow and exercise performance. Another pathway has been identified, in which nitrate (NO_3) is reduced to nitrite (NO_2), and eventually to NO[13].

Studies employing pomegranate and beetroot have also shown to increase blood flow and vessel dilation. These results indicate the enhancement done by NO production. In studies conducted by Trexler and Melvin (2014)[13, 23]; 19 highly active men and women (Age: 22.2 ±2.2 yrs; Height: 174.8 ±10.7 cm; Body mass: 71.9±13.5kg) participated and performed regular exercise for at least 2 months, and were not on any prescription drugs or supplements that might alter the results of the study. Pomegranate extract or placebo (1000mg) was given to the participants, both PE and PL (in a form of 500mg capsules). Each one of the 19 participants worked up 3 treadmill runs until exhaustion. Runs were done at 90%, 100% and 110% peak velocity of the treadmill, and the time to exhaustion was recorded for each run. Blood pressure was measured and ultrasound was used to measure blood flow and vessel diameter. PE intake aided in the production of NO that caused vasodilatation. This study has produced significant results and shown that ingestion of the pomegranate extract was found to significantly increase time to exhaustion, vessel diameter and blood flow which result in delays of fatigue and exhaustion in highly active athletes[13,23]. While research with pomegranate juice has indicated improved recovery from exercise as stated above, more research is needed to investigate the effects of PE on exercise recovery and the underlying mechanisms.

Recent studies have shown that dietary NO_3 supplementation increased the circulating plasma [NO_2], and reduced the O_2 cost of submaximal exercise in healthy humans. Nitrate was ingested as part of a healthy diet; vegetables are estimated to contain about 60–80% of the daily NO_3 intake in a western diet; green leafy vegetables such as lettuce, spinach and beetroot are particularly rich in NO_3. Ingested inorganic NO_3 is rapidly absorbed from the intestines and a peak blood plasma NO_3 observed 1 hour following NO_3 ingestion. There is now evidence that the muscle ATP turnover at a fixed work rate is reduced and the mitochondrial phosphate/Oxygen ratio is increased following NO_3 supplementation, which suggests important insights into the physiological bases for the reduced VO_2 during exercise[24]. Nitrate (NO_3) supplementation has also been shown to improve exercise performance in both healthy and patient populations. Thus, dietary NO_3 supplementation may represent an effective method to improve exercise efficiency and exercise tolerance in humans. Therefore, an NO_3^--rich diet may have numerous cardiovascular and other health benefits including exercise performance[24]. These results were supported by some evidence that nitrate supplementation reduces the O_2 cost of endurance exercise and thus increasing the efficiency of energy production[24, 51]. Other studies have revealed that NO_3 supplementation may reduce the muscle production of ATP cost and increase the efficiency of mitochondrial respiration[24]. These findings have practical implications in

enhancing sporting performance, and improving quality of life in both athlete and elderly population.

To substantiate the above findings, a study in 201026, investigated the effect of dietary supplementation with sodium nitrate or placebo (NaCl) for 2 days before the test (what is found in 100-300 g of a nitrate-rich vegetable such as spinach or beetroot). The exercise tests consisted of an incremental exercise to exhaustion with combined arm and leg. The results showed a significant reduction in VO2 max during maximal exercise using a large active muscle mass and improved the energetic function of the working muscles26. To prove the benefit, a study was done, by Murphy and his Colleagues 27, to examine whether whole beetroot consumption to increase nitrate intake and improve endurance exercise performance where 11 fit men and women underwent two 5-km treadmill trials in random sequence, one 75 minutes after consuming baked beetroot (200g with-500mg nitrate) and the other 75 minutes after consuming cranberry relish as a placebo. It was found that mean running velocity during the 5-km run tended to be faster after beetroot consumption (12.3± 2.7 vs 11.9± 2.6 km/hour). During the last 1.1 miles of the 5-km run, running velocity was 5% faster (12.7± 3.0 vs 12.1± 2.8 km/hour) in the beetroot trial. No differences in heart rate were observed between trials; however, perceived exertion was lower with beetroot. The authors concluded that consumption of nitrate-rich whole beetroot improves running performance in healthy adults, whereas nitrates from other sources may have detrimental health effects[27].

Lack of exercise and inactivity have an adverse effect on endurance and overall well-being as shown in some studies; one was done in 2005[4], where 16 healthy male volunteers, spent 25 days of bed rest showed a 13% reduction in femoral artery diameter. Another study[4] showed impaired acetylcholine-mediated increase in forearm blood flow after 13 days of bed rest, while others have demonstrated that as little as 7 days of bed rest can reduce basal blood flow and vasodilatation in the skin microcirculation[4]. While these examples of in-activities uniformly show a reduction in vasodilator capacity and structural remodeling, they need to be interpreted with caution as their extreme nature may not accurately represent a "real life" sedentary human lifestyle. Muggeridge and collegues[28] had done a study on eight trained kayakers who performed trials of 15 min of paddling at 60% of maximum work rate, five 10-s all-out sprints, and a 1 km time trial. They ingested 70 ml nitrate-rich concentrated beetroot juice (BR) or tomato juice (placebo). VO_2 during steady-state exercise was lower in the BR trial than in the PL trial ($p= 0.01$), despite that, BR ingestion appears to have no effect on repeated supra-maximal sprint of kayaking performance[28].

Urea nitrogen and Creatine kinase: The effect of polyphenols on endurance using Amarkand tubers (21 species found all over India) was studied. Methanol extracts of 4 Amrakand tubers species of the *Dioscorea bulbifera* were assessed at 1 mg/ml concentration. All species exhibited high content of polyphenols. *D bulbifera bulbils* and *E. ochreata* significantly prolonged the swimming endurance time of the female rats tested. Urea nitrogen and Creatine kinase were significantly reduced by treatment of *D. bulbifera* bulbils and *E. ochreata* as compared to negative control. It was also found that D. *bulbifera* bulbils effectively increased creatine ($p<0.001$), lactate dehydrogenase ($p < 0.01$) and haemoglobin ($p < 0.001$) levels compared to negative control. *D. bulbifera bulbils* and *E. ochreata* treatments were also significantly increased glycogen content ($p < 0.05$, $p < 0.01$) and lowered malondialdehyde levels ($p < 0.001$) in muscles and in liver tissue[19]. This study could be considered to be relevant since both urea and nitrogen and creatine kinase are produced when muscles are inflamed and damaged which indicates tissue damage that can be reversed by the effect of polyphenols ingestion which contributes to better stamina. More studies are needed to investigate the cellular and molecular components of these findings to understand the mechanisms of regulation of glucose transport genes or through inflammatory pathways against fatigue and exercise endurance.

VO_2 max*:* A supplement contained Pomegranate Fruit Extract was taken 30 minutes before each CrossFit workout. Subjects also were given a whey protein and carbohydrate supplement mixed with water and consumed immediately after each CrossFit workout session. Twenty nine participants were recruited to complete three varied workouts per week. The study produced beneficial results by increasing power (74.40%) of the participants and maintaining VO_2 max (78.16%)[32]. Further research should be conducted to determine what other possible sport-related benefits may be achieved with the proprietary blend supplements such as recovery during extended competition.

In order to achieve endurance after a strenuous exercise, both pain and inflammation of the working muscles need to be controlled. Studies have suggested the protective action of tart cherry juice extract against inflammation and pain. Thirty six male and eighteen female runners ran an average of 26.3±2.5 km over a 24 hour period. The runners ingested 355 mL bottles of tart cherry juice or placebo twice daily for 7 days before and on the day of the race. Participants evaluated their pain level on a VAS at baseline, before and after the race. It was reported that runners who had cherry juice experienced less muscular pain after the race compared to the ones who had placebo[33]. In order to improve endurance of long distance, studies have focused on possible beneficial nutrients for athletes such as blackcurrant juice and extract which are full of polyphenolic antioxidants[34]. Although some of these polyphenols are lost during the juicing procedure.

Other polyphenols: Untrained males who took green tea extract for four weeks and exercise-induced oxidative damage indicators were measured. After four weeks of scheduled training and supplementation, muscular endurance test was performed on upper and lower body. The supplemented group had increased plasma total polyphenols, antioxidant status, and decreased creatine kinase activity 24-hours post-exercise[29]. Black current extract was tested on 13 active males on high-intensity intermittent running and post-running lactate responses were estimated[30]. Active runners (age: 25±4 yrs, height: 1.82 ±0.07 m, body mass: 81±14 kg) were put on a protocol of treadmill running to the point of exhaustion. The runners consumed capsulated black current extract (300 mg/day CurraNZ; containing 105 mg anthocyanin) or placebo for 7 days. Blood samples containing lactate were collected after 30 min post-exhaustion. The extract has significantly increased total running distance by 10.6%, with the distance during sprints increased by 10.8%. At exhaustion, blood lactate tended to be higher for the extract takers. As a result blackcurrant extract may improve running performance in greater distances, and there was higher lactate at exhaustion[30]. The relationship between the amount of exercise-induced muscle damage and the release of enzymes; creatine kinase (CK), aspartate aminotransferase (AST), and lactate dehydrogenase (LD) was examined in rats. The course of exercise elicited histological damage only in the soleus muscle, and significant plasma CK, AST, and LD elevations were found immediately post-exercise both in male and female rats. Moreover, the release of enzymes was significantly greater in males than in females. An increase in the exercise duration from 1.5 h to 2.5 h resulted in a disproportional increase in both histological muscle damage and muscle enzyme release[31].

Table 1. Summary of Studies on Endurance Exercise showing their brief results

No.	Endurance Study	Results	notes
1	Labonte, K, et al[18]	Creatine Kinase, lactate, and reactive oxygen species (ROS). Repetitive high intensity workout may overwhelm the body systems and prevents detoxification	human
2	Kerksick, C. et al[20]	An increase in Glutathione reductase enzyme level in serum	human
3	Konig, D, et al[21]	**O**xidative stress has been associated with decreased physical performance, muscular fatigue, muscle damage, and overtraining	human
4	Musumeci, G, et al.[22]	extra-virgin oil can improve the body defence against oxidative stress	rats
5	Trexler, ET. Et al[13] Melvin, M, et al. [23]	NO has been identified as a vital contributor to the vasodilation observed after exercise. Pomegranate extract was found to increase time to exhaustion, vessel diameter and blood flow which result in delays of fatigue and exhaustion in highly active athletes.	human
6	Lundberg, J, et al[24]	An NO_3^--rich diet may have numerous cardiovascular and other health benefits including exercise performance	human
7	Larsen, FJ, et al [26]	A moderate dietary dose of nitrate showed a significant reduction in VO_2 max	human
8	Murphy, M.et al. [27]	consumption of nitrate-rich whole beetroot improves running performance in healthy adults.	human
9	Muggeridge, D, et al[28]	Beet root ingestion appears to have no effect on repeated supra-maximal sprint of kayaking performance	human
10	Narkhede, A, et al [19]	Urea nitrogen and Creatine kinase were significantly reduced by treatment	human
11	Labonte, K, et al [18]	Prolonged swimming endurance time of the female rats tested. Urea nitrogen and Creatine kinase were significantly reduced.	rats
12	Outlaw, J, et al.[32]	Beneficial results by increasing power (74.40%) of the participants and maintaining VO_2 max (78.16%)	human
13	Kuehl, KS, et al.[33]	It was reported that runners who had cherry juice experienced less muscular pain after the race compared to the ones who had placebo	human
14	Jurgoński, A , et al. [34]	Cherry juice improved endurance	human
15	Ewa Jówko.[29]	Green tea group had increased plasma total polyphenols, antioxidant status, and decreased creatine kinase activity 24-hours post-exercise.	human
16	Perkins, IC, et al [30]	Blackcurrant extract may improve running performance in greater distances with higher lactate at exhaustion	human
17	Meulen, JH, et al.[31]	An increase in the exercise duration from 1.5 h to 2.5 h resulted in a disproportional increase in both histological muscle damage and muscle enzyme release	rats

Strength Exercise

Pomegranate: A study on humans was performed to determine if polyphenol supplementation of ellagitannins in pomegranate extract improves recovery of muscle

strength and soreness and diminished markers of inflammation and cellular stress during the 4 day recovery period after performing an aberrant exercise. Healthy males were recruited and supplemented with PE or PL (500mL were taken twice daily) at 12 hour intervals for the 9-day testing period. Subjects performed the eccentric exercise round 15 min on the 5th day of the experiment, after the pre-exercise measurements of isometric strength, soreness test using a VAS of 0 to 10 scale. Profound strength recovery improvement 48-72 hour after eccentric exercise was determined when PE was supplemented, muscle soreness was significantly reduced in the PE group at 2 hour after exercise[36].

***Other polyphenols*:** Green tea possesses high amounts of caffeine and catechin polyphenols. Green tea extract is one of the most common herb that has been suggested to affect weight loss and is now considered to be the fourth most popular dietary supplement in the US[34]. Research suggests that catechin polyphenols possess antioxidant properties that are associated with decreased cardiovascular disease and has also been shown to increase energy expenditure by stimulating brown adipose tissue thermogenesis which consequently improve lean body mass. It was also demonstrated that green tea catechin consumption enhanced the exercise-induced changes in abdominal fat due the increase in building muscles[29,37]. This was suggested to burn more fat and especially in the abdominal area because it is considered to be the least exercised part of the body causing further accumulation of fat in this area.

Creatine, Lactate and branched amino acids: Omega-3 supplements have been found to produce consistent results as those with ellagitannins of pomegranate. A study where participants received Omega-3 dietary supplementation for 30 days prior to heavy eccentric exercise, and some received a placebo supplement for the same 30-day period. Forearm extensions performed with the non-dominant arm to its maximum to induce muscle soreness. VAS was used and recorded as a score from 0-10 at intervals of 0, 24, 48, 72, and 96 hours. Both C-reactive protein (CRP) and creatine kinase were measured, as well as blood lactate levels that were immediately analyzed after the exercise. It was found that at 72 and 96 hours there were significant differences between the two groups in delayed onset of muscle soreness (DOMS). Group 1 reported mean pain scores of 2.19 ± 1.92 vs. 4.36 ± 3.17 in placebo ($p = 0.031$) at 72 hours and 1.63 ± 1.77 vs 3.17 ± 2.75 ($p = 0.035$) at 96 hours. Therefore dietary intake of an omega-3 supplement leads to a higher N3 Index level and decreased DOMS in healthy individual[39]. On the other hand, dried grape remains after pressing to produce juice (pomace) was studied to investigate if its potent antioxidant content applied in rats *in vivo* during swimming exercise. Grape pomace extract (possesses *in vitro significant antioxidant* properties) demonstrated high capacity to remove the DPPH and ABTS radicals and protected against Free Radical- Induced DNA Damage[**40**]. Generally, it was suggested that endurance exercise was able to influence muscle mass and muscle strength, yet the effect seemed to diminish beyond the age of 70 years[40].

Muscle strength requires variety of nutrients in addition to antioxidants. A blend of branched chain amino acids, quercetin, co-enzymated B-vitamins, creatine monohydrate, alanyl-glutamine, and natural nitrate from pomegranate and beet root extracts was prepared. Twenty resistance-trained males were randomly assigned to consume the blend or a placebo 30 minutes prior to exercise. All had participated in an 8-week, 3-day per week, resistance-training programme including leg press, bench press, and bent-over rows. Muscle thickness of the quadriceps was measured by Ultrasonography, Dual-Energy X-ray Absorptiometry (DEXA) and lean body mass, were determined. Blend supplementation resulted in a significant ($p < 0.01$) increase in bench press strength (18.4% vs. 9.6%) compared with placebo after 4 and 8 weeks of training. There were no significant effect of intake in leg press strength ($p = 0.08$). But the blend ingestion resulted in a significant increase in lean body mass (7.8% vs. 3.6%) and quadriceps muscle thickness (11.8% vs. 4.5%) compared with placebo[42]. Additional research should investigate if supplementation with the

blend would result in better adaptations than intake with each of the ingredients alone.

Table 2. Summary of Studies on strength Exercise with their brief results

No.	Strength Study	Results	Notes
1	Trombold, JR, et al[9]	ellagitannins in pomegranate extract improved recovery of muscle strength and soreness and reduced markers of inflammation and cellular stress	human
3	Ewa Jówko[29] Maki, KC, et al [37]	Green tea catechins consumption enhanced the exercise-induced changes in abdominal fat due the increase in muscles building	human
4	Lembke, P, et al[39]	Omega-3 supplement lead to a higher N3 Index level and decreased DOMS in healthy individual	human
5	Aristidis, S, et al[40]	Protected against Free Radical-Induced DNA damage	human
6	Lowery, R, et al[42]	Blend ingestion resulted in a significant increase in lean body mass and quadriceps muscle thickness	human

Exercise Recovery

Recovery after exercise depends on intensity of the work exerted on muscle, and the extent at which muscle is damaged. Many factors may play a role in muscle damage; however the exact mechanism is not well understood yet. Some explanation of this mechanism refers to the damage to the ryanodine receptors of the sarcoplasmic reticulum resulting in elevated intracellular calcium ion concentration. Increased intracellular calcium may lead to muscle damage through activation of calcium-dependent proteolytic chemical pathways and increased muscle protein degradation. Muscle damage causes inflammation in the micro-environment recruiting neutrophils and macrophages. These immune cells release ROS and NO derivatives as well as pro-inflammatory cytokines. Therefore, antioxidants, more specifically polyphenols might be beneficial in fixing the damage.

Pomegranate: The effect of pomegranate juice on the recovery of muscle soreness and biomarkers of muscle damage after a weight lifting training was studied on 9 male elite weightlifters (age: 21±0.5 years, body mass: 80±9.5 kg, height 175±8.1cm). Supplements of 1500 ml placebo or pomegranate juice were taken three times daily in the 48 hour that preceded the two training sessions, in addition to the 500 ml of each 1 hour before the training sessions. Each 500mL of the given pomegranate juice contained 2.56g of total polyphenol containing 292.6mg of flavonoids, 1.08g of orthodiphenols, and 46.75mg of flavonols. The training session consisted of 5 sets of Olympic-Weightlifting exercises: snatch, squat and clean and jerk. To assess the exertion of heavy lifting on muscles, a scale of 6 (very light) to 20 (very hard) was used where participants expressed their feelings of fatigue, soreness, and comfort using this scale. The study showed that consuming the pomegranate juice intake during weightlifting training decreased the pain and delayed responses of the muscle damage and inflammation, and muscle soreness (knee flexor), accelerated the recovery kinetic of the biological parameters, and improved the weightlifting performance[43]. Given the small sample size, further studies should verify these results using greater sample size of athletes. Moreover, pain and soreness expression can vary greatly from one person to another and using such scale might widely be inaccurate.

Another study conducted on trained weight lifters and has been found that 15 days of drinking pomegranate juice (250 ml twice daily) improved the arm strength during the period post exercise and reduced significantly the elbow flexor muscle soreness for 48 and 72 hours post exercise. However, isometric strength and muscle soreness in the knee extensors were not significantly affected[44]. Dosage of pomegranate supplement was found to be equally if not

more important to consider in order to seek ultimate benefit. This was tested by Machin et al[45] and they showed that either once-daily or twice-daily pomegranate juice supplementation improved recovery of both leg and arm muscles after an unconventional exercise.

Other polyphenols: A study tested the effect of a cherry juice concentrate on recovery after intensive knee extensor resistance training in individuals who were highly active and well-trained, along with oxidative damage and inflammation indicators. Participants were seated on the knee extension machine, and consumed 30 mL twice per day of either cherry juice concentrate or a fruit concentrate placebo. Participants alternated between legs in each trial and did 3 sets with 5 repetitions. Blood analysis, biomechanical recording, and pressure pain threshold were taken. Consumption of the cherry juice concentrate for 7 days before, the day of, and 2 days after completing a round of intensive knee extensor resistance training enhanced recovery of isometric muscle strength[46]. This outcome was accompanied by a reduction in oxidative stress presumably because of the anti-inflammatory and antioxidative properties of polyphenols in cherries. It was also found that tart cherry juice reduced muscle pain during running[33]. In addition, polyphenols decreased strength loss after damaging exercis[31]. Green tea extract decreased respiratory exchange ratio during aerobic exercise practiced after seven days of intake[29].

Soy beverage consumption effect on recovery of damaged tissues after training was also studied. Ten adult males consumed a soy beverage (2 servings/day, 40g protein and 44 mg of the isoflavone, genistein/day) for 3 weeks[48]. The plasma total antioxidant status values increased in all participants. On the other hand, the 10 other males consumed a whey beverage (40g protein/day) depressed plasma total antioxidant status values. Both soy and whey consumption were also tested for their effects on muscle tissue breakdown after a bout of strenuous aerobic exercise, which is a form of oxidant stress. The bout was performed before and after the 3 weeks study and soy produced a lower rise in plasma creatine kinase activity; an indicator of muscle tissue breakdown, whereas whey produced a higher rise. Soy also reduced the post-exercise rise in plasma myeloperoxidase, an indicator of inflammatory oxidant stress. In addition, soy maintained, while whey decreased, the post-exercise rise in plasma uric acid which can be inversely proportional to oxidant activity. These results provide evidence that soy can exert antioxidant effects in people, particularly for exercise-induced oxidative stress[48].

Table 3. Summary of Studies on Exercise Recovery with their brief results

No.	Recovery study	Results	Notes
1	Ammar , A, et al.[43]	Pomegranate juice decreased the pain and delayed responses of the muscle damage, inflammation, muscle soreness, accelerated the recovery kinetic of the biological parameters, and improved the weightlifting performance	human
2	Trombold, JR, et al [44]	Pomegranate juice improved the arm strength and reduced significantly the elbow flexor muscle soreness.	human
3	Machin, D , et al[45]	Pomegranate juice supplementation improved recovery of both leg and arm muscles after an unconventional exercise	human
4	Bowtell, JL, et al[46]	Cherry concentrate enhanced recovery of isometric muscle strength.	human
5	Kuehl et al [33]	Tart cherry juice reduced muscle pain during running, and polyphenols decreased strength loss after damaging exercise	human
6	Ewa Jówko[29]	Green tea extract decreased respiratory exchange ratio during aerobic exercise practiced after seven days of intake	human
7	Rossi, A, et al [48]	Soy can exert antioxidant effects in people after exercise-induced oxidative stress	human

Conclusion

The majority of studies showed the benefits of polyphenols intake on exercise performance. However, such effect of polyphenols should be further elucidated and still needs further research, and thus, more investigations need to be carried out in human bio-systems in addition to in virto and/or animals studies to obtain more scientific and applicable results. Polyphenolic compounds from different sources can enhance fitness modelled in better endurance, strength, and recovery after exercise. However, many of these enhancements occurred in combination with other non polyphenolic nutrients, like proteins and carbohydrates.

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Abbreviations

ABTS: Azino-bis-benzothiazoline-sulphonic acid is a substrate for peroxidase enzyme; BP: Blood pressure; DPPH: Diphenyl-picrylhydrazyl method; FRAP: Ferric reducing anti-oxidant power; FMD: flow mediated dilation; GAE/L: Gallic Acid Equivalence/liter; HR: Heart rate; HPLC–DAD: high-performance liquid chromatography with Diode –Array Detection; LDL: low density lipoprotein; MMPs: matrix metalloproteinase; NO: Nitrogen Oxide; PE: pomegranate extract; pomegranate juice: PJ; PL: Placebo; ROS: Reactive Oxygen species; SPO2: Oxygen saturation; VAS: Visual analogue scale; VO2 max: maximal oxygen consumption.

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الفواكه والمكملات الغذائية الغنية بمركبات البوليفينولك لتعزيز أداء التمرين

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ملخص

من المقبول على نطاق واسع أن ممارسة التمارين الرياضية بانتظام تمثل عاملاً مهماً لتحسين الصحة؛ للحصول على فوائد رائعة يمكنك الحصول عليها في المدى القصير والطويل. لتمهيد الطريق لأداء أفضل في ممارسة الرياضة من خلال تحسين قوة الجسم والحد من مخاطر إصابات العضلات، تناول كمية من العناصر الغذائية المناسبة تعد أمر حيوي. هناك العديد من أنواع المغذيات الموجودة في الوجبات الغذائية لدينا والتي هي ضرورية، ولكن بعضها يحتوي على قيم إضافية. البوليفينول لا ينظر فقط في التوافر البيولوجي الشخصي، ولكن لخصائصها المضادة للأكسدة وكذلك الإجراءات المفيدة المتنوعة.

الهدف: الغرض من هذا الاستعراض هو توفير معلومات سائدة عن تأثير الفواكه الغنية بالبوليفينول والمكملات البوليفينول من مصادر مختلفة على أداء التمارين الرياضية. وعادة ما يتم تصميم الأداء من خلال القوة، والقدرة على التحمل، والانتعاش.

الخلاصة: نتيجة لما أظهرته العديد من الدراسات المقدمة في هذا الاستعراض، تبين أن البوليفينول للحد من المؤشرات الحيوية الإجهاد التأكسدي، وزيادة تدفق الدم، وزيادة إمدادات غاز O_2، والحد من تلف العضلات، وبالتالي تحسين الانتعاش، والقدرة على التحمل، والقوة في الأفراد النشطين جسديا.

الكلمات الدالة: أداء التمرين، قدرة التحمل، الرمان، البوليفينول، الأكسدة، الشوارد الحرة.

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