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NITRATE SUPPLEMENTATION AND ATHLETIC PERFORMANCE: A NARRATIVE REVIEW

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ABSTRACT

This narrative review investigates the impact of nitrate supplementation on physical performance across endurance, intermittent, and strength exercises. Nitrate, ingested through beetroot juice, has shown potential ergogenic benefits, including enhanced vasodilation, mitochondrial efficiency, and muscle contractility. Studies indicate that nitrate supplementation can improve time trial performance, power output, and reduce oxygen cost in endurance exercises. For intermittent and strength exercises, findings suggest increased repetitions, total weight lifted, and reduced muscle fatigue. However, variability in study designs, participant characteristics, supplementation protocols, and exercise modalities contribute to mixed results. Additionally, many studies suffer from small sample sizes and short durations, limiting the ability to draw definitive conclusions about long-term effects and safety. Placebo effects and individual variability further complicate the interpretation of results. While some studies suggest clear performance enhancements, the precise mechanisms remain unclear. Furthermore, most research predominantly involves male participants, highlighting the need for studies on female athletes. Future research should focus on standardizing protocols, increasing sample sizes, and exploring personalized supplementation strategies. Overall, nitrate supplementation through beetroot juice presents a promising, evidence-based approach to enhancing various aspects of athletic performance, but further investigation is needed.

Key words: Beetroot juice. Physical performance. Ergogenic aids. Nitric oxide. Sports nutrition.

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RESUMO

Suplementação de nitrato e desempenho esportivo: uma revisão narrativa

Esta revisão narrativa investiga o impacto da suplementação de nitrato no desempenho físico em exercícios de endurance, intermitentes e de força. O nitrato, ingerido através do suco de beterraba, tem mostrado potenciais benefícios ergogênicos, incluindo aumento da vasodilatação, eficiência mitocondrial e contratilidade muscular. Estudos indicam que a suplementação de nitrato pode melhorar o desempenho em testes contrarrelógio, na produção de potência e reduzir o custo de oxigênio em exercícios de resistência. Para exercícios intermitentes e de força, os achados sugerem aumento das repetições, do peso total levantado e redução da fadiga muscular. No entanto, a variabilidade nos desenhos dos estudos, características dos participantes, protocolos de suplementação e modalidades de exercício contribuem para resultados mistos. Adicionalmente, muitos estudos sofrem com tamanhos de amostra pequenos e durações curtas, limitando a capacidade de tirar conclusões definitivas sobre os efeitos a longo prazo e a segurança. Efeitos placebo e variabilidade individual complicam ainda mais a interpretação dos resultados. Embora alguns estudos sugiram melhorias claras no desempenho, os mecanismos precisos permanecem incertos. Além disso, a maioria das pesquisas envolve predominantemente participantes masculinos, destacando a necessidade de estudos com atletas femininas. Pesquisas futuras devem focar na padronização dos protocolos, aumento dos tamanhos de amostra e exploração de estratégias de suplementação personalizadas. Em geral, a suplementação de nitrato através do suco de beterraba apresenta uma abordagem promissora e baseada em evidências para melhorar diversos aspectos do desempenho atlético, mas são necessárias investigações adicionais.

Palavras-chave: Suco de beterraba. Desempenho físico. Recursos ergogênicos. Óxido nítrico. Nutrição esportiva.

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INTRODUCTION

Enhancing strength, increasing muscle mass, reducing body fat, improving aerobic capacity, reducing fatigue, and accelerating muscle recovery are common goals among athletes and fitness enthusiasts (Becker and collaborators, 2016).

Consequently, there has been a significant increase in the use of dietary supplements to address potential nutritional gaps and achieve these objectives (Júnior, 2016).

However, many products on the market lack substantial scientific evidence supporting their efficacy. Nitrate is one of the few nutritional ergogenics with robust evidence demonstrating its positive effects on sports performance (Naderi and collaborators, 2016; Maughan and collaborators, 2018; Pelling and collaborators, 2019).

Nitrate (NO_3^-) is a compound found in vegetables, and its supplementation has demonstrated benefits for physical performance (Ghiarone and collaborators, 2014). Daily nitrate consumption ranges from 30 to 180 mg, with approximately 80% derived from vegetables, notably beetroot, which is one of the richest sources (>250 mg of NO3-/100g) (Loureiro, Santos, 2017).

According to the International Olympic Committee, consuming 5 to 9 mmol of nitrate (310 to 560 mg) 2 to 3 hours before exercise can enhance performance, with prolonged intake (>3 days) also showing benefits (Maughan and collaborators, 2018).

Beetroot juice is used as a supplement due to its palatability and high nitrate content (Domínguez and collaborators, 2018), which, when converted to nitrite (NO_2^-), increases nitric oxide (NO) bioavailability (Kelly and collaborators, 2013). Additionally, beetroot juice contains beneficial phytochemicals like ascorbic acid, carotenoids, betalains, phenolic acids, and flavonoids (Clifford and collaborators, 2015).

The pigments betacyanin (purple) and betaxanthin (yellow) contribute to its colour (Kanner, Harel, Granit, 2001).

The benefits of beetroot juice are linked to increased nitric oxide (NO) levels, as dietary nitrate is converted to nitrite and then NO (Carlstrom, Montenegro, 2018).

After absorption in the upper gastrointestinal tract, part of the dietary nitrate returns to the oral cavity via salivary secretion and is reduced to nitrite by commensal bacteria, increasing serum nitrate and NO levels (Stecker and collaborators, 2019).

NO regulates cardiovascular function, blood pressure, and blood flow (Kelly and collaborators, 2014), relaxing smooth muscle in blood vessels, enhancing vasodilation and blood flow to muscles during exercise (Olsson and collaborators, 2019), and benefiting oxygen kinetics and nutrient delivery (Bailey and collaborators, 2009).

NO also reduces oxygen cost, especially in hypoxic conditions (Domínguez and collaborators, 2018; Richards and collaborators, 2018), improving exercise tolerance (Shete, Bute, Deshmukh, 2014).

Since 2010, research on nitrate supplementation's effects on sports performance has increased, with mixed results. Some studies report positive effects (Wylie and collaborators, 2019; Woessner and collaborators, 2018; San Juan and collaborators, 2020), while others do not (Lowings and collaborators, 2016; Alves, 2018).

These variations may be due to differences in exercise type, dosage (Domínguez and collaborators, 2018), physical conditioning, and gender (Ocampo and collaboratos, 2018).

This narrative review aims to evaluate the effects of nitrate supplementation on physical performance in endurance, intermittent, and strength exercises.

By analysing the current literature, the review seeks to clarify nitrate supplementation's potential benefits and limitations and provide insights into its practical applications for athletes and coaches.

To prepare this narrative review, a comprehensive bibliographic search was conducted.

This search included original scientific articles and review papers found in the PubMed, Web of Science, and Google Scholar databases, with no restrictions on the time.

Sources and Bioavailability of Nitrate

Nitrate (NO_3^-) intake primarily derives from vegetables, particularly leafy greens (such as spinach, arugula, celery, and lettuce) and root vegetables like beetroot, which contains approximately 250 mg of NO_3^- per 100 g.

The nitrate content in these foods can vary significantly due to climate (temperature, humidity, solar radiation, etc.), soil nitrate

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concentration, use of fertilisers, and plant cultivars.

For instance, observed a variation of approximately 300% of nitrate content in beetroot.

Dietary nitrate in beetroot juice is rapidly absorbed in the gastrointestinal tract following ingestion, subsequently entering systemic circulation (Figure 1).

After absorption, a substantial portion of the nitrate (~75%) is excreted by the kidneys as urea, while about 25% is recycled back to the oral cavity through entero-salivary circulation. A small fraction (4-8%) of the nitrate concentrated in saliva is reduced to nitrite (NO_2^-) by anaerobic commensal bacteria on the surface of the tongue (Ocampo and collaborators, 2018).

Upon swallowing and reaching the stomach, some of the nitrite may be converted to nitric oxide (NO) and other reactive oxygen species due to the acidic pH environment (Koch and collaborators, 2017).

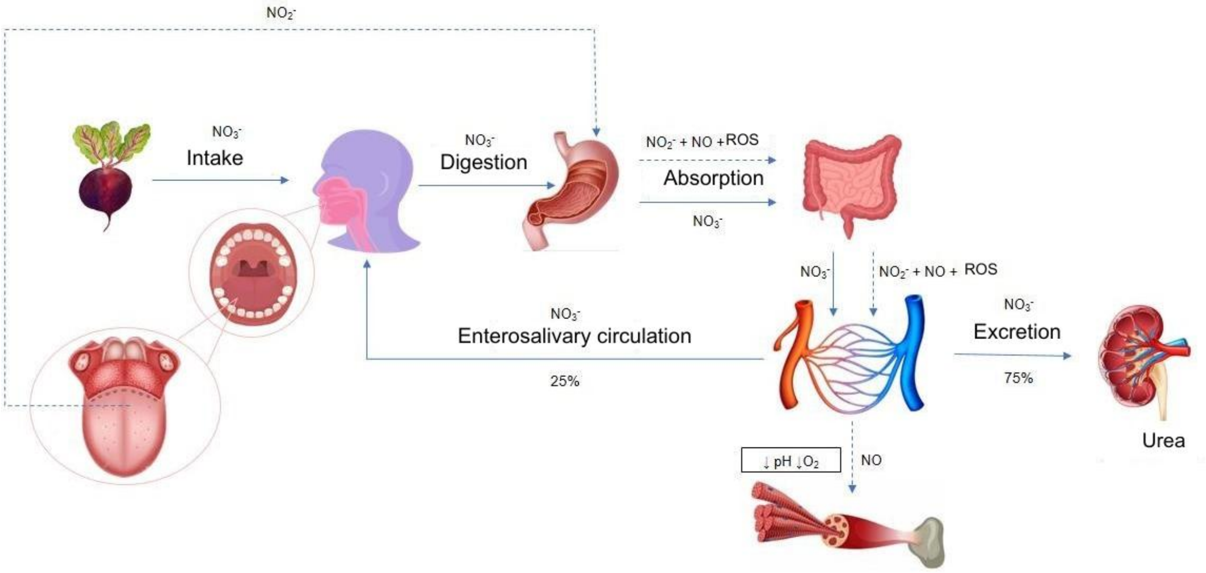

Figure 1 - Nitrate Bioavailability. ROS (Reactive Oxygen Species), NO_3^- (nitrate), NO_2^- (nitrite), NO (nitric oxide). When nitrate in beetroot juice is ingested, it is rapidly absorbed by the gastrointestinal tract and enters systemic circulation. Approximately 75% of the ingested nitrate is excreted as urea, while 25% returns to the oral cavity through active transport via salivary secretion (solid line). A portion of the nitrate in saliva is reduced to nitrite on the surface of the tongue by anaerobic commensal bacteria. Once swallowed and reaching the stomach, some of the nitrite is converted into nitric oxide and other reactive oxygen species, which then enter systemic circulation. During conditions of acidic pH and low oxygen concentration, such as in muscles during physical activity, the remaining nitrite is converted into nitric oxide (dashed line).

The remaining NO_2^- enters systemic circulation, where it can be reduced to NO during conditions of hypoxia and acidosis (Koch and collaborators, 2017).

These conditions frequently arise during physical exercise, during which NO acts on muscle fibers to decrease muscle tone, thereby enhancing vasodilation. This mechanism assists in regulating blood flow, promoting mitochondrial biogenesis, and reducing the oxygen cost of exercise (Domínguez and collaborators, 2018; McDonagh and collaborators, 2019).

Consequently, this pathway can be seen as a reservoir that ensures NO availability when oxygen delivery is restricted, such as during high-intensity exercise where oxygen supply to muscle cells diminishes (Casey, Joyner, 2011).

It is noteworthy that nitrate levels peak in the blood approximately 1 to 2 hours after ingestion, while nitrite levels peak about 2 to 3 hours post-ingestion. Both return to baseline concentrations within 24 hours (Senefeld and collaborators, 2020).

Therefore, nitrate supplementation in the form of beetroot juice exhibits its most potent ergogenic effect when consumed 2 to 3 hours before physical exercise.

Furthermore, the use of antibacterial mouthwashes and chewing gum should be avoided during the supplementation period, as these products can reduce the oral concentration of nitrate-reducing bacteria, thereby impairing the absorption and conversion of plasma nitrite and ultimately affecting NO formation (Govoni and collaborators, 2008; Coggan and collaborators, 2018; Senefeld and collaborators, 2020).

Despite the reported benefits on sports performance, the consumption of beetroot juice with a high nitrate concentration may increase the risk of forming nitroso compounds with potential carcinogenic effects, which are stimulated by NO.

Although the nitrate present in beetroot juice does not pose a direct health risk, its capacity to elevate blood NO levels and, consequently, nitroso compounds warrant further investigation in physically active individuals. In this context, it is worth noting that if supplementation is conducted acutely, the concomitant intake of vitamin C with beetroot juice may be a viable alternative to reduce the formation of such nitroso compounds (Berends and collaborators, 2019).

Metabolism and Physiological Effects of Nitric Oxide

Nitric oxide (NO) is a highly lipophilic gaseous molecule with a free radical and a short half-life (3 to 9 seconds). It can be found both in the environment and endogenously produced within the body. NO plays crucial physiological roles in the cardiovascular, immune, and nervous systems (Neilly and collaboratos, 1994; Zhao, Vanhoutte, Leung, 2015). This review emphasizes its functions related to muscle tissue and athletic performance.

NO can be synthesized in the body via two distinct pathways. The first pathway involves nitric oxide synthase (NOS) enzymes, which include three isoforms: endothelial (eNOS), neuronal (nNOS), and inducible (iNOS). These enzymes catalyze the oxidation of the amino acid L-arginine into NO and L-citrulline, utilizing NADPH and O2 as co-substrates (Stuehr, 2004; Zago, Zanesco, 2006).

The second pathway is independent of NOS enzymes and involves the reduction of dietary nitrate (NO_3^-), found in foods like beetroot juice, to nitrite (NO_2^-), and subsequently to NO.

This process is enhanced under hypoxic and acidic conditions, where NOS activity is low (Clements, Lee, Bloomer, 2014).

The final step in this pathway is facilitated by enzymes and proteins such as deoxyhemoglobin, xanthine oxidoreductase, and components of the electron transport chain, which aid in the conversion of NO_2^- to NO (McDonagh and collaborators, 2019).

Once formed, NO exerts numerous physiological effects. It reduces inflammation and regulates mitochondrial respiration, particularly at complexes I and IV of cytochrome c. NO also activates guanylyl cyclase (GC), increasing levels of cyclic guanosine monophosphate (cGMP).

Elevated cGMP activates protein kinase G (PKG), which promotes vasodilation and mitochondrial biogenesis (Lidder, Webb, 2012).

This leads to significant reductions in systolic blood pressure and the energetic cost of performing physical tasks, thereby enhancing exercise tolerance (Jones, 2014; Ashworth and collaborators, 2015).

NO also plays a significant role in improving mitochondrial efficiency. Mitochondria are the powerhouses of cells, responsible for producing ATP through oxidative phosphorylation. NO enhances the efficiency of mitochondria by reducing the amount of oxygen required for ATP production (Larsen collaborators, 2011).

This effect allows for greater endurance and reduced fatigue during prolonged exercise sessions. Studies have shown that nitrate supplementation leads to a significant reduction in the oxygen cost of exercise, indicative of enhanced mitochondrial efficiency (Bailey and collaborators, 2015; Jones, 2014).

Another critical mechanism by which nitrate supplementation enhances exercise performance is through improved calcium handling in muscle cells. Calcium ions play a pivotal role in muscle contraction by binding to troponin, which initiates the interaction between actin and myosin, the proteins responsible for muscle contraction.

NO influences the release and reuptake of calcium ions in the sarcoplasmic reticulum of muscle cells, leading to more efficient and powerful muscle contractions (Haider, Folland, 2014).

This improvement in calcium handling can enhance muscle strength and power, which are crucial for resistance training performance (Ferguson and collaborators, 2013).

Phosphocreatine (PCr) serves as a rapidly mobilizable reserve of high-energy phosphates in skeletal muscle.

During high-intensity exercise, PCr is broken down to produce ATP, the primary energy currency of the cell. Nitrate supplementation has been shown to accelerate the recovery of PCr stores following exercise, allowing for quicker replenishment of ATP and sustained high performance during repeated bouts of high-intensity efforts (Bailey and collaborators, 2015; Vanhatalo and collaborators, 2010).

This mechanism is particularly beneficial for resistance training, where repeated maximal or near-maximal efforts are common (Pinna and collaborators, 2014).

Effects on Endurance Exercise Performance

Numerous studies have demonstrated the beneficial effects of nitrate supplementation on endurance exercise performance (Table 1), such as significant increases in average power output, reductions in time trial performance, decreased systolic blood pressure (SBP), and improved time to exhaustion (Lansley and collaborators, 2011; Satyanand, Vali, Krishna, 2014; Santana and collaborators, 2019). However, some studies have not found positive effects on running economy, maximal oxygen uptake (VO_2 max), perceived fatigue, or time trial performance (Boorsma, Spriet, Whitfield, 2014; Fernández and collaborators, 2018; Shannon and collaborators, 2017).

Studies by Santana and collaborators (2019), Lansley and collaborators (2011), and Satyanand, Vali, and Krishna (2014) demonstrated positive effects on time trial performance with nitrate supplementation. Santana and collaborators, (2019) evaluated sixteen healthy recreational male runners, divided into nitrate and placebo groups. The nitrate group ingested 750 mg/day (~12 mmol) of nitrate plus 5 g of resistant starch, while the placebo group consumed 6 g of resistant starch for 30 days.

The study found a significant decrease in 10 km time trial time in the nitrate group during the first and second weeks, which remained stable thereafter. Lansley and collaborators, (2011) studied nine competitive male cyclists who consumed 0.5 L of beetroot juice (6.2 mmol of NO_3^-) or nitrate-depleted beetroot juice (0.0047 mmol of NO_3^-) 2.5 hours before a 4 km and 16.1 km cycling time trial. The results showed that beetroot juice increased plasma [nitrite], reduced completion time by an average of 2.8% in the 4 km test and 2.7% in the 16.1 km test, and increased average power during both tests.

Satyanand, Vali, and Krishna (2014) conducted a study with 100 healthy male volunteers aged 12-30 years, divided into placebo and beetroot juice groups.

The beetroot juice group consumed 250 ml of concentrated beetroot juice for nine weeks. The results demonstrated a reduction in systolic blood pressure (123 ± 1.6 vs. 121 ± 1.4 with placebo) and improved 6-minute free running time trial performance (464 ± 114.7 meters vs. 410 ± 78.7 meters).

Shannon and collaboratos (2017) and Fernández and collaborators (2018) showed mixed results, with some performance improvements but no significant effects in certain tests. Shannon and collaborators (2017) evaluated eight trained male runners or triathletes. BRJ supplementation (140 ml, ~12.5 mmol NO_3^-) or placebo (~0.01 mmol NO_3^-) was administered 3 hours before 1500 m and 10,000 m time trials.

The study found that BRJ significantly increased plasma [NO_2^-] and resulted in faster performance in the 1500 m TT (319.6 ± 36.2 vs. 325.7 ± 38.8 s), but no significant difference in the 10 km TT.

Fernández and collaborators (2018) conducted an experiment with twelve elite male middle- and long-distance runners. Participants consumed nitrate-rich beetroot juice (6.5 mmol NO_3^-/70 ml) or placebo (0.065 mmol NO_3^-/70 ml) daily for 15 days. The NO3- group showed improvements in perceived exertion (RPE), vastus lateralis oxygen saturation, and time to exhaustion compared to the placebo group, but no substantial improvements in other physiological or biomechanical variables.

A study by Boorsma, Spriet, and Whitfield (2014) found no significant improvement in performance, highlighting variability in responses to nitrate supplementation.

The authors conducted a randomized, double-blind, crossover study with eight elite male long-distance runners. Participants used BRJ supplementation (210 ml, 19.5 mmol NO_3) or placebo 2.5 hours before tests for 8 days.

The study showed increased plasma nitrate with both acute and chronic

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supplementation but no improvement in time trial performance, with only two individuals showing time improvements.

It was notable in several studies that NO_3^- supplementation resulted in reduced execution time and increased plasma [NO_2^-] (Lansley and collaborators, 2011; Shannon and collaborators, 2017; Santana and collaborators, 2019), showing efficacy in both acute and chronic supplementation. Improvements in RPE, vastus lateralis oxygen saturation, and time to exhaustion were also demonstrated (Fernández and collaborators, 2018).

Conversely, other studies showed no variation in VO_2 max and resting blood pressure (Lansley and collaborators, 2011; Boorsma, Spriet, Whitfield, 2014; Shannon and collaborators, 2017).

This suggests that chronic consumption, as demonstrated by Satyanand, Vali, and Krishna (2014) over nine weeks, may yield different results than acute consumption, as in the study by Boorsma, Spriet, and Whitfield (2014) over eight days.

Table 1 - Effects of Nitrate Supplementation on Endurance Exercise Performance.

Study	Participants	Dose	Test	Results
Lansley and collaborators, 2011	9 competitive male cyclists	6.2mmol 2.5h before	4 and 16.1km time trial on cycle ergometer	Increased plasma NO_2^-. Decreased completion time. Increased average power. No change in VO2 during the test
Satyanand, Vali and Krishna, 2014	100 healthy volunteers of both sexes	250ml for 9 weeks	Free running time trial for 6 minutes	Decreased systolic blood pressure and increased distance covered
Boorsma, Spriet and Whitfield, 2014	8 elite long-distance male runners	19.5mmol for 8 days 2.5h before	Submaximal 1.5km run at 50, 65, and 80% of peak VO2 on indoor track, measured on day 1 and 8	Increased plasma NO_3^- on both days and no change in VO2max and performance improvement
Shannon and collaborators, 2017	8 trained male runners or triathletes	12.5mmol 3h before	1.5km treadmill TT on the 1st visit, 10km on the 2nd, 3rd to 6th alternating 1.5 and 10km with and without NO3- each	Increased plasma NO_2^-. No change in resting blood pressure and VO2max. Increased serum lactate and speed only in 1.5km
Fernández and collaborators, 2018	12 elite middle- and long-distance male runners	6.5mmol in breakfast for 15 days	Treadmill run in 4 stages of 3 minutes each at 10, 15, 17.1 and 20 km/h, then increasing 0.2 km/h every 12s until exhaustion	Improved perceived exertion, O2 saturation of the vastus lateralis, and time to exhaustion. No change in running economy and leg stiffness
Santana and collaborators, 2019	16 recreational male runners	12mmol 3 times a day for 30 days	10km running time trial 3 times a week	Decreased test time from week 1 to 2, but stable in week 3 and 4. Lactate concentration remained stable

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Effects on Intermittent and Strength Exercise Performance

Substantial evidence demonstrates the benefits of nitrate supplementation for intermittent and strength exercises (Table 2).

Various studies have observed reductions in heart rate, subjective perception of effort (RPE), muscle soreness, and fatigue, as well as increases in the number of repetitions in strength exercises, total weight lifted, average power, time to exhaustion, reduction in sprint execution time, and improved peak power achievement (Nogueira Viebig, 2015; Mosher and collaborators, 2016; Wylie and collaborators, 2016; Nyakayiru and collaborators, 2017; Cuenca and collaborators, 2018; Jonvik and collaborators, 2018; Husmann and collaborators, 2019; Sanchez and collaborators, 2020).

However, other research has not found positive effects, reporting no differences in fatigue index, maximal voluntary isometric contractions, oxidative stress, local or general fatigue indicators, or voluntary activation, among others (Clifford and collaborators, 2016; Mosher and collaborators, 2016; Cuenca and collaborators, 2018; Husmann and collaborators, 2019).

Several studies have demonstrated the benefits of nitrate supplementation on high-intensity intermittent exercise performance. Nyakayiru and collaborators, (2017) conducted a randomized, double-blind, crossover study with 32 male soccer players, showing that six days of beetroot juice (BRJ) ingestion improved performance.

Participants consumed 140 ml (~12.9 mmol NO_3^-) of nitrate-rich or nitrate-depleted beetroot juice three hours before the tests. BRJ increased plasma and salivary NO_3^- and NO_2^- concentrations and improved the distance covered by an average of 3.4 ± 1.3%, with a lower average heart rate, highlighting its ergogenic benefits.

Similarly, Wylie and collaborators (2016) evaluated ten male team sport players over five days of nitrate-rich beetroot juice (8.2 mmol NO_3^-) and placebo supplementation. They found that beetroot juice significantly increased average power in short, repeated maximal intensity exercises with short recovery periods, though not in longer intervals or with extended recovery durations, indicating that nitrate supplementation may enhance performance in specific high-intensity intermittent exercises. The effects of nitrate supplementation on recovery from intermittent exercise were investigated by Clifford and collaborators (2016).

The authors examined the impact of beetroot juice on recovery between two repeated sprint tests in 20 male team sport players. Participants consumed either a placebo or beetroot juice (2 x 250 mL) for three days following an initial sprint test and before a second test.

Although the study found no significant differences in sprint performance, maximal voluntary isometric contractions, or biochemical markers, beetroot juice reduced declines in counter-movement jump performance and relative force index, indicating some recovery benefits.

Studies have demonstrated that nitrate supplementation can enhance resistance training performance. Mosher and collaborators (2016) evaluated 12 men with three years of resistance training experience who ingested 70 ml of concentrated beetroot juice (6.4 mmol NO_3^-) or a placebo for six days. Participants performed bench press exercises at 60% of one-repetition maximum (1RM) for three sets to failure.

The study found significant increases in repetitions to failure and total weight lifted with nitrate supplementation. Similarly, Sanchez and collaborators (2020) studied 12 healthy recreationally trained men performing incremental training tests (free squat and bench press) at 60%, 70%, and 80% of 1RM.

Participants ingested 70 ml of concentrated beetroot juice (6.4 mmol NO_3^-) or a placebo two hours before each test. Results showed more repetitions in the nitrate group, especially at 60% and 70% 1RM, but no differences at 80% 1RM, suggesting nitrate supplementation is more effective at lower intensities.

Research has shown that nitrate supplementation can enhance high-intensity short-duration exercise performance. Cuenca and collaborators (2018) conducted a randomized, double-blind, placebo-controlled crossover study with 15 healthy men who ingested 70 ml of beetroot juice (6.4 mmol NO_3^-) or a placebo three hours before a 30-second Wingate test.

The results indicated that beetroot juice improved peak and average power and reduced time to peak power.

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Likewise, Jonvik and collaborators, (2018) studied 52 athletes, including elite, competitive, and recreational participants, who consumed 140 ml of nitrate-rich beetroot juice (~800 mg/day) or nitrate-depleted beetroot juice daily for six days. Although peak and average power did not differ significantly between groups across three Wingate tests, the nitrate group showed improved time to peak power, suggesting benefits for high-intensity tasks.

Nitrate supplementation has been shown to enhance endurance in strength training and improve sprint performance. Nitrate supplementation has been shown to enhance endurance in strength training and improve sprint performance.

Husmann and collaborators (2019) conducted a randomized, double-blind, placebo-controlled crossover study with 12 recreationally active men. After five days of nitrate supplementation via beetroot juice (~6.5 mmol NO3- per 70 ml) or a placebo, participants performed a high-intensity knee extensor exercise test to exhaustion.

The study found that nitrate supplementation improved time to exhaustion, reduced perceived exertion, and decreased muscle soreness, indicating enhanced exercise tolerance and recovery. In another study, Nogueira and Viebig (2015) conducted a randomized, double-blind, crossover, placebo-controlled trial with nine adolescent female handball athletes who ingested 500 ml of beetroot juice or a placebo three hours before a running test of 6 x 18 m sprints with 10-second intervals. The study found a significant reduction in execution time in the beetroot juice group, suggesting benefits for intermittent sprint performance.

Table 2 - Effects of nitrate supplementation on Performance in Intermittent and Strength Exercises.

Study	Sample	Dose	Test	Results
Nogueira and Viebig, 2015	9 female handball players	250ml pure juice 3h before	6x18m running sprint with 10s interval	Decreased test execution time. No significant change in BP, HR, and RPE
Mosher and collaborators, 2016	12 men with resistance training experience	6.4mmol for 6 days, test after	3 sets of bench press at 60% of 1RM to failure with 2 minutes rest	Increased total weight lifted and repetitions to failure. No change in blood lactate and RPE
Clifford and collaborators, 2016	20 male team sports players	250ml 30m after each attempt and 250ml with evening meal for 3 days	20x30m maximum effort sprints with 30s recovery	Counter movement jumps, relative force index, and pain threshold were higher
Wylie and collaborators, 2016	10 men familiar with high-intensity intermittent exercise	8.2mmol divided morning and night for 6 days	From day 3: 24x6s 24s rec., 7x30s 240s rec., 6xMax 60s 60s recovery on ergometer bike	Increased NO_2^-. Increased average power only in 24x6s. Increased blood lactate in 24x6s and 7x30s
Nyakayiru and collaborators, 2017	32 amateur male soccer players	12.9mmol 3h before	2x20m sprints with progressively increasing speed with 10s rest	Increased plasma and salivary NO_3^-. Average improvement in distance covered. Decreased heart rate
Cuenca and collaborators, 2018	15 men with resistance training experience	6.4mmol 3h before	30s Wingate test on ergometer bike	Decreased time to reach peak power. Improved peak and average power. No change in fatigue index, RPE, and lactate levels
Jonvik and collaborators, 2018	52: 10 elite (5 men, 5 women), 22 competitive	800mg with breakfast for 6 days	3 Wingate tests with 4 min recovery,	No change in peak and average power. Improved time to peak power

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	(14 men, 8 women), and 20 recreational (10 men, 10 women)		cycling against 50 Watts resistance	
Husmann and collaborators, 2019	12 recreationally active men	6.5mmol every morning and 2h before for 5 days	High-intensity single-leg dynamic knee extensor exercise at 85% peak power until exhaustion	Improved time to exhaustion. Lower voluntary maximum torque and quadriceps contraction torque. Decreased muscle fatigue, RPE, and leg muscle pain. No change in voluntary activation
Sanchez and collaborators, 2020	12 men with resistance training experience	6.4mmol 2h before	3 sets of free squat and bench press at 60, 70, and 80% of 1RM	Increased reps only at 60 and 70% in squat. No change in blood lactate, movement speed, and perceived effort

Overall, the consumption of nitrate-rich beetroot juice has shown to increase the number of repetitions and total weight lifted in resistance exercises (Mosher and collaborators, 2016; Sanchez and collaborators, 2020), improve peak and average power in high-intensity short-duration exercises (Cuenca and collaborators, 2018), and enhance recovery and performance in specific intermittent exercise protocols (Wylie and collaborators, 2016; Jonvik and collaborators, 2018).

However, the effects may vary based on dosage, duration of supplementation, and type of exercise, as evidenced by studies reporting mixed results (Clifford and collaborators, 2016; Husmann and collaborators, 2019; Nogueira Viebig, 2015).

These findings suggest that while nitrate supplementation can be beneficial, its effectiveness may depend on various factors and further research is needed to optimize its use for different types of exercise.

Limitations of This Study

Despite promising findings on nitrate supplementation and exercise performance, several limitations must be acknowledged. First, the reviewed studies show considerable variability in design, including differences in participant characteristics, supplementation protocols, exercise modalities, and outcome measures, making direct comparisons challenging and contributing to mixed results.

Second, many studies involved small sample sizes, limiting statistical power and increasing the risk of type II errors. Larger, well-powered studies are needed to confirm the benefits and explore individual variability. Third, most studies were short-term, leaving the long-term effects and safety of chronic supplementation unclear.

Fourth, placebo effects may account for some observed performance improvements, as participants' expectations could influence their performance.

Fifth, there is significant individual variability in response to supplementation, influenced by genetic factors, baseline dietary nitrate intake, and fitness levels, necessitating personalized approaches.

Sixth, the studies did not always account for participants' overall diet and lifestyle factors, which could influence the effects of supplementation.

Finally, many studies predominantly included male participants, with limited research on the effects in female athletes, highlighting the need for more research to understand sex differences in response to supplementation.

Practical Applications

Recommended Dosage and Timing (Silva and collaborators, 2022):
- Acute Ingestion:** Consume 5–14.9 mmol of nitrate at least 150 minutes before exercise.
- Chronic Ingestion:** Consume 5–9.9 mmol of nitrate daily for ≥2 days.

Types of Supplementation

- Beetroot Juice is the most common form due to its high nitrate content and palatability. Choose products that specify their nitrate content to ensure adequate dosing.
- Other dietary sources of nitrate include spinach, arugula, celery and lettuce. Adding these vegetables to daily meals provides a natural and consistent source of nitrate, contributing to the overall ergogenic benefits. Beetroot juice and a high-nitrate diet offer greater ergogenic benefits than nitrate salts.

Factors Affecting Nitrate Bioavailability

- Antibacterial Mouthwashes and Chewing Gum: Avoid use as they can reduce the effectiveness by disrupting oral bacteria necessary for nitrate conversion to nitrite.
- Individual Responses: Consider genetic factors, baseline dietary nitrate intake, and overall fitness levels (The ergogenic effect is more pronounced in individuals with lower aerobic fitness).

Safety

- The current literature suggests that acute dietary nitrate supplementation in doses up to approximately 16 mmol/day is likely safe and does not increase health risks such as cancer, methemoglobinemia, hypotension, or renal injury.

However, chronic nitrate supplementation over several months is not recommended.

Additionally, it is recommended that nitrate supplementation be administered through vegetables or vegetable juices rich in antioxidants, as these compounds mitigate the formation of N-nitrosamines (Shannon and collaborators, 2022).

CONCLUSION

The evidence reviewed in this study highlights the significant potential of nitrate supplementation, particularly through beetroot juice, to enhance exercise performance across various types of physical activities.

The ergogenic effects of nitrate are attributed to its role in increasing nitric oxide (NO) bioavailability, which in turn improves vasodilation, oxygen delivery, mitochondrial efficiency, and muscle contractility.

These physiological benefits are evident in endurance, intermittent, and strength training exercises.

Thus, nitrate supplementation represents a promising, evidence-based strategy to enhance various aspects of athletic performance.

Future research should continue to explore the long-term effects, optimal dosing strategies, and individual variability to refine guidelines for its use in sports nutrition. By integrating nitrate supplementation into their training regimens, athletes can potentially achieve better performance outcomes and faster recovery, contributing to overall athletic success.

REFERENCES

1-Alves, L.S. Efeitos da suplementação de nitrato sobre o desempenho em testes de ciclismo, corrida e natação: uma revisão sistemática. TCC Bacharelado em Educação Física. Universidade Tecnológica Federal do Paraná. Curitiba. 2018.

2-Ashworth, A.; Mitchell, K.; Blackweel, J.R.; Vanhatalo, A.; Jones, A.M. High-nitrate vegetable diet increases plasma nitrate and nitrite concentrations and reduces blood pressure in healthy women. Public Health Nutrition. Vol. 18. Num. 14. 2015, p. 2669-2678.

3-Bailey, S.J.; Varnham, R.L.; DiMenna, F.J.; Breese, B.C.; Wylie, L.J.; Jones, A.M. Inorganic nitrate supplementation improves muscle oxygenation, O_2 uptake kinetics, and exercise tolerance at high but not low pedal rates. Journal of applied physiology. V. 118 Num. 11. 2015 p.1396-1405.

4-Bailey, S.J.; Winyard, P.; Vanhatalo, A.; Blackwell, J.R.; Dimenna, F.J.; Wilkerson, D.P.; Tarr, j.; Benjamin, N.; Jones, A.M. Dietary nitrate supplementation reduces the O2 cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans. Journal of Applied Physiology. Rockville. Vol. 107. Num. 4. 2009. p. 1144-1155.

5-Becker, L.K.; Pereira, A.N.; Pena, G.E.; Oliveira, E.C.; Silva, M.E. Efeitos da suplementação nutricional sobre a composição corporal e o desempenho de

RBPFEX
Revista Brasileira de Prescrição e Fisiologia do Exercício

atletas: uma revisão. Revista Brasileira de Nutrição Esportiva. São Paulo. Vol.10. Num. 55. 2016. p. 93- 111.

6-Berends, J.E.; Van Den Berg, L.M.M.; Guggeis, M.A.; Henckens, N.F.T.; Hossein, I.J.; De Joode, M.E.J.R.; Zamani, H; Van Pelt, K.A.A.J.; Beelen, N.A.; Kuhnle, G.G.; De Kok, T.M.C.M.; Van Breda, S.G.J. Consumption of nitrate-rich beetroot juice with or without vitamin C supplementation increases the excretion of urinary nitrate, nitrite, and N-nitroso compounds in humans. International Journal of Molecular Sciences. Vol. 20. Num. 9. 2019. p. 1-15

7-Boorsma, R.K.; Whitfield, J.; Spriet, L.L. Beetroot juice supplementation does not improve performance of elite 1500-m runners. Med Sci Sports Exerc. Vol. 46. Num. 12. 2014. 2326-2334.

8-Carlstrom, M.; Montenegro, F. Therapeutic value of stimulating the nitrate-nitrite-nitric oxide pathway to attenuate oxidative stress and restore nitric oxide bioavailability in cardiorenal disease. Journal of Internal Medicine. Vol. 285. Num. 1. 2018. p. 2-18.

9-Casey, D.P.; Joyner, M.J. Local control of skeletal muscle blood flow during exercise: influence of available oxygen. Journal of Applied Physiology. Vol. 111. Num. 6. 2011. p. 1527-1538.

10-Clifford, T.; Howatson, G.; West, D.J.; Stevenson, E.J. The potential benefits of red beetroot supplementation in health and disease. Nutrients. Vol. 7. 2015. p. 2801-2822.

11-Clifford, T.; Berntzen, B.; Davison, G.W.; West, D.J.; Howatson, G.; Stevenson, E.J. Effects of beetroot juice on recovery of muscle function and performance between bouts of repeated sprint exercise. Nutrients. Vol. 8. Num. 8. 2016. p. 506.

12-Clements, W.T.; Lee, S.R.; Bloomer, R.J. Nitrate Ingestion: A Review of the Health and Physical Performance Effects. Nutrients. Vol. 6. Num. 11. 2014. p. 5224-5264.

13-Coggan, A.R.; Broadstreet, S.R.; Mikhalkova, D.; Bole, I.; Leibowitz, J.L.; Kadkahodayan, A.; Park, S.; Thomas, D.P.; Thies, D.; Peterson, L.R. Dietary nitrate-induced increases in human power: high versus low responders. Physiological Reports. Vol. 6. Num. 2. 2018. p. 1-8.

14-Cuenca, E.; Jodra, P.; Pérez-López, A.; González-Rodríguez, L.G.; Fernandes da Silva, S.; Veiga-Herreros, P.; Domínguez, R. Effects of beetroot juice supplementation on performance and fatigue in a 30-s all-out sprint exercise: a randomized, double-blind cross-over study. Nutrients. Vol. 10. Num. 9. 2018. p. 1222.

15-Domínguez, R.; Maté-Muñoz, J.L.; Cuenca, E.; García-Fernández, P.; Mata-Ordoñez, F.; Lozano-Estevan, M.C.; Veiga-Herreros, P.; da Silva, S.F.; Garnacho-Castaño, M.V. Effects of beetroot juice supplementation on intermittent high-intensity exercise efforts. Journal of the International Society of Sports Nutrition. Vol. 15. Num.1. 2018. p. 2.

16-Ferguson, S.K. ; Hirai, D.M. ; Copp, S.W.; Holdsworth, C.T.; Allen, J.D.; Jones, A.M.; Musch, T.I.; Poole, D.C. Effects of nitrate supplementation via beetroot juice on contracting rat skeletal muscle microvascular oxygen pressure dynamics. Respiratory physiology & neurobiology. Vol.187 Num. 3. 2013. p.250-255.

17-Fernández, C.; Moraleda, B.; Cupeiro, R.; Peinado, A.B.; Butragueño, J.; Benito,P.J. The effects of beetroot juice supplementation on exercise economy, rating of perceived exertion and running mechanics in elite distance runners: A double-blinded, randomized study. PloS one, Vol. 13. Num. 7. 2018. p. e0200517.

18-Ghiarone, T.; Ataide, T.; Bertuzzi, R.; Lima-Silva, A.E. Suplementação de nitrato e sua relação com a formação de óxido nítrico e exercício físico. Acta Brasileira do Movimento Humano. Vol. 4. Num. 4. 2014. p. 103-135.

19-Govoni, M.; Jansson, E.A.; Weitzberg, E.; Lundberg, J.O. The increase in plasma nitrite after a dietary nitrate load is markedly attenuated by an antibacterial mouthwash. Nitric Oxide. Vol. 19. Num. 4. 2008. 333-337.

20-Haider, G.; Folland, J.P. Nitrate supplementation enhances the contractile properties of human skeletal muscle. Medicine and science in sports and exercise. Vol. 46 Num.12. 2014 p. 2234-2243.

21-Husmann, F.; Bruhn, S.; Mittlmeier, T.; Zschorlich, V.; Behrens, M. Dietary nitrate supplementation improves exercise tolerance by reducing muscle fatigue and perceptual responses. Frontiers in physiology. Vol. 10. 2019. p. 404.

22-Jones, A.M. Dietary nitrate supplementation and exercise performance. Sports medicine. Vol. 44. Num. 1. 2014. p. 35-45.

23-Júnior, M.P. Efeito da suplementação de aminoácidos de cadeia ramificada no desempenho físico humano. Revista Brasileira de Nutrição Esportiva. São Paulo. Vol. 10. Num. 56. 2016. p.157-164.

24-Kanner, J.; Harel, S.; Granit, R. Betalains - a new class of dietary cationized antioxidants. Journal of Agricultural and Food Chemistry. Vol. 49. Num. 11. 2001. p. 5178-5185.

25-Kelly, J.; Vanhatalo, A.; Bailey, S.J.; Wylie, L.J.; Tucker, C.; List, S.; Winyard, P.G.; Jones, A.M. Dietary nitrate supplementation: effects on plasma nitrite and pulmonar O2 uptake dynamics during exercise in hypoxia and normoxia. American Physiological Society. Vol. 307. Num. 7. 2014. p. 920-930.

26-Kelly, J.; Fulford, J.; Vanhatalo, A.; Blackwell, J.R.; French, O.; Bailey, S.J.; Gilchrist, M.; Winyard, P.G.; Jones, A.M. Effects of short-term dietary nitrate supplementation on blood pressure, O2 uptake kinetics, and muscle and cognitive function in older adults. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology. Vol. 304. Num. 2. 2013. p. R73-R83.

27-Koch, C.D.; Gladwin, M.T.; Freeman, B.A.; Lundberg J.O.; Weitzberg, E.; Morris A. Enterosalivary nitrate metabolism and the microbiome: intersection of microbial metabolism, nitric oxide, and diet in cardiac and pulmonary vascular health. Free Radical Biology and Medicine. Vol. 105. 2017. p. 48-67.

28-Jonvik, K.L.; Nyakayiru, J.; Van Dijk, J.W.; Maase, K.; Ballak, S.B.; Senden, J.M.; Van Loon, L.J.C.; Verdijk, L.B. Repeated-sprint performance and plasma responses following beetroot juice supplementation do not differ between recreational, competitive and elite sprint athletes. European journal of sport Science. Vol. 18. Num. 4. 2018. p. 524-533.

29-Lansley, K.E.; Winyard, P.G.; Bailey, S.J.; Vanhatalo, A.; Wilkerson, D.P.; Blackwell, J.R.; Gilchrist, M.; Benjamin, N.; Jones, A.M. Acute dietary nitrate supplementation improves cycling time trial performance. Med Sci Sports Exerc. Vol. 43. Num. 6. 2011. p.1125-1131.

30-Larsen, F.J.; Schiffer, T.A.; Borniquel, S.; Sahlin, K.; Ekblom, B.; Lundberg, J.O.; Weitzberg, E. Dietary inorganic nitrate improves mitochondrial efficiency in humans. Cell metabolismo. Vol. 13. Num. 2. 2011. p. 149-159.

31-Lidder, S.; Webb, A.J. Vascular effects of dietary nitrate (as found in green leafy vegetables and beetroot) via the nitrate-nitrite-nitric oxide pathway. British Journal of Clinical Pharmacology. Vol. 75. Num. 3. 2012. p. 677-696.

32-Loureiro, L.L.; Santos, G.B. Nitrato: suplementação, fontes dietéticas e efeitos na performance. Revista Brasileira de Nutrição Funcional. Vol. 36. Num. 71. 2017. p. 7-16.

33-Lowings, A.; Shannon, O.M.; Deighton, K.; Matu, J.; Barlow, M.J. Effect of Dietary Nitrate Supplementation on Swimming Perfomance in Trained Swimmers. International Journal of Sport Nutrition and Exercise Metabolism. Vol. 26. Num. 4. 2016, p. 377-384.

34-Maughan, R.J.; Burke, L.M.; Dvorak, J.; Larson-Meyer, D.; Peeling, P.; Phillips, S.M.; Rawson, E.S.; Walsh, N.P.; Garthe, I.; Geyer, H.; Meeusen, R.; Van Loon, L.J.C.; Shirreffs, S.M.; Spriet, L.L.; Stuart, M.; Vernec, A.; Currell, K.; Ali, V.M.; Budgett, R.G.; Engebretsen, L. IOC consensus statement: Dietary supplements and the high-

RBPFEX
Revista Brasileira de Prescrição e Fisiologia do Exercício

performance athlete. British Journal of Sports Medicine. Vol. 52. Num. 7. 2018. p. 439-455.

35-McDonagh, S.T.J.; Wylie, L.J.; Thompson, C.; Vanhatalo, A.; Jones A. M. Potention benefits of dietary nitrate ingestion in healthy and clinical populations: A brief review. European Journal of Sport Science. Vol. 19. Num. 1. 2019, p. 15-29.

36-Mosher, S.L.; Sparks, S.A.; Williams, E.L.; Bentley, D.J.; Mc Naughton, L.R. Ingestion of a Nitric Oxide Enhancing Supplement Improves Resistance Exercise Performance. J Strength Cond Res. Vol. 30. Num. 12. 2016, p. 3520-3524.

37-Naderi, A.; Oliveira, E.P.; Ziegenfuss, T.N.; Willems, M.T. Timing, optimal dose and intake duration of dietary supplements with evidence-based use in sports nutrition. Journal of Exercise Nutrition & Biochemistry. Vol. 20. Num. 4. 2016. p. 1-12.

38-Neilly, P.J.D.; Kirk, S.J.; Gardiner, K.R.; Rowlands, B.J. The L-arginine/nitric oxide pathway - Biological properties and therapeutic applications. Ulster Medical Journal. Vol. 63. Num. 2. 1994, p. 193-200.

39-Nogueira, T.D.R.; Viebig, R.F. Efeitos ergogênicos do consumo de suco de beterraba em adolescentes do gênero feminino praticantes de handebol. Revista Brasileira de Prescrição e Fisiologia do Exercício. São Paulo. Vol. 9. Num. 56. 2015. p. 635-642.

40-Nyakayiru, J.; Jonvik, K.L.; Trommelen, J.; Pinckaers, P.J.M.; Senden, J.M.; Van Loon, L.J.C.; Verdijk, L.B. Beetroot juice supplementation improves high-intensity intermittent type exercise performance in trained soccer players. Nutrients. Vol. 9. Num. 3. 2017. p. 314-324.

41-Ocampo, D. A. B.; Paipilla, A. F.; Marin, E.; Vargas-Molina, S.; Petro, J. L.; Perez-Idárraga, A. Dietary Nitrate from Beetroot Juice for Hypertension: A Systematic Review. Biomolecules. Vol. 8. Num. 4. 2018. p. 134-146.

42-Olsson, H.; Al-Saadi, J.; Oehler, D.; Pergolizzi, J.; Magnusson, P. Physiological Effects of Beetroot in Athletes and Patients. Cureus. Vol. 11. Num. 12. 2019. p. 1- 11.

43-Pelling, P.; Castell; L.M.; Derave, W.; De Hon, O.; Burke, L.M. Sports Foods and Dietary Supplements for Optimal Function and Perfomance Enhancement in Track- and-Field Athletes. International Journal of Sport Nutrition and Exercise Metabolism. Vol. 29. Num. 2. 2019. p. 198-209.

44-Pinna, M.; Roberto, S.; Milia, R.; Marongiu, E.; Olla, S.; Loi, A.; Migliaccio, G. M.; Padulo, J.; Orlandi, C.; Tocco, F.; Concu, A.; Crisafulli, A. Effect of beetroot juice supplementation on aerobic response during swimming. Nutrients. Vol. 6 Num. 2. 2014. p.605-615.

45-Richards, J.C.; Racine, Matthew, L.R.; Hearon Jr., C. M.; Kinkel, M.; Luckasen, G.J.; Larson, D.G.; Allen, J.D.; Dienno, F.A. Acute ingestion of dietary nitrate increases muscle blood flow via local vasodilation during handgrip exercise in young adults. Physiological Reports. Vol. 6. Num. 2. 2018, p. 1-12.

46-San Juan, A.F.; Dominguez, R.; Lago-Rodríguez, A.; Montoya, J.J.; Tan, R.; Bailey, S.J. Effects of Dietary Nitrate Supplementation on Weightlifting Exercise Performance in Healthy Adults: A Systematic Review. Nutrients. Vol. 12. Num. 8. 2020, p. 1- 16.

47-Sanchez, A.; Bernier, V.M.; Villagran, D.; Alonso, C.; Cantarero, F.J.; Perez, J.; Castro, J.M. Acute effects of beetroot juice supplements on resistance training: a randomized double-blind crossover. Nutrients. Vol. 12. Num. 7. 2020. p. 1912.

48-Santana, J.; Madureira, D.; França, E.; Rossi, F.; Rodrigues, B.; Fukushima, A.; Billaut, F.; Lira, F.; Caperuto, E. Nitrate supplementation combined with a running training program improved time-trial performance in recreationally trained runners. Sports. Vol. 7. Num. 5. 2019. p. 120.

49-Satyanand, V.; Vali, S.M.; Krishna, B.P. A study of beet root derived dietary nitrate efficacy on performance of Runners. Ind. J. Basic Appl. Med. Vol. 3. 2014. p. 690-695.

50-Senefeld, J.W.; Wiggins, C.C; Regimbal, R.J.; Dominelli, P.B.; Baker, S.R.; Joyner, M.J. Ergogenic Effect of Nitrate Supplementation: A Systematic Review and Meta analysis. Medicine and Science in Sports and Exercise. Philadelphia. Vol. 52. Num. 10. 2020. p. 2250-2261.

51-Shannon, O.M.; Allen, J.D., Bescos, R.; Burke, L., Clifford, T.; Easton, C.; Gonzalez, J.T.; Jones, A.M.; Jonvik, K.L.; Larsen, F.J.; Peeling, P.; Piknova, B.; Siervo, M.; Vanhatalo, A.; McGawley, K.; Porcelli, S. Dietary Inorganic Nitrate as an Ergogenic Aid: An Expert Consensus Derived via the Modified Delphi Technique. Sports medicine. Vol. 52. Num.10. 2022. p. 2537-2558.

52-Shannon, O.M.; Barlow, M.J.; Duckworth, L.; Williams, E.; Wort, G.; Woods, D.; Siervo, M.; O'Hara, J.P. Dietary nitrate supplementation enhances short but not longer duration running time-trial performance. European journal of applied physiology. Vol. 117. Num. 4. 2017. p. 775-785.

53-Shete, A.N.; Bute, S.S.; Deshmukh, P.R. A Study of VO2 Max and Body Fat Percentage in Female Athletes. Journal of Clinical and Diagnostic Research. Vol. 8. Num. 12. 2014. p. 1-3.

54-Silva, J.C.L.; Meira Lins, N.C.; Santos Gomes, W.; Campos, E.Z.; Santos Costa, A. Suplementação de nitrato no desempenho durante exercício intermitente de alta intensidade: uma revisão de literatura. Revista Brasileira de Nutrição Esportiva. São Paulo.Vol.16. Num. 96. 2022. p. 53-62.

55-Stecker, R.A.; Harty, P.S.; Jagim, A.R.; Candow, D.G.; Keksick, C.M. Timing of ergogenic aids and micronutrients on muscle and exercise performance. Journal of International Society of Sports Nutrition. Vol. 16. Num. 37. 2019, p. 1-8.

56-Stuehr, D.J. Enzymes of the L-arginine to nitric oxide pathway. Journal of Nutrition. Vol. 134. Num. 10. 2004. p. 2748S-2751S.

57-Vanhatalo, A.; Bailey, S.J.; Blackwell, J.R.; DiMenna, F.J.; Pavey, T.G.; Wilkerson, D.P.; Benjamin, N.; Winyard, P.G.; Jones, A.M. Acute and chronic effects of dietary nitrate supplementation on blood pressure and the physiological responses to moderate-intensity and incremental exercise. American journal of physiology. Regulatory, integrative and comparative physiology. Vol. 299 Num. 4. 2010. p. 1121 p.1131.

58-Wylie, L.J.; Park, J.W.; Vanhatalo, A.; Kadach, S.; Black, M.I.; Stoyanov, Z.; Schechter, A.N.; Jones, A.M. Human skeletal muscle nitrate score: influence of dietary nitrate supplementation and exercise. The Journal of Physiology. Vol. 597. Num. 23. 2019, p. 5565-5576.

59-Wylie, L.J.; Ortiz De Zevallos, J.; Isidore, T.; Nyman, L.; Vanhatalo, A.; Bailey, S.J.; Jones, A.M. Dose-dependent effects of dietary nitrate on the oxygen cost of moderate- intensity exercise: Acute vs. chronic supplementation. Nitric Oxide - Biology and Chemistry. Cambridge. Vol. 57. 2016. p. 30-39.

60-Woessner, M.N.; Mcllvenna, L.C.; Zevallos, J.O.; Neil, C.J.; Allen, J.D. Dietary nitrate supplementation in cardiovascular health: an ergogenic aid or exercise therapeutic? American Journal of Phisiology. Vol. 312. Num. 2. 2018. p. 195-212.

61-Zago, A.S.; Zanesco, A. Óxido nítrico, doenças cardiovasculares e exercício físico. Arquivos Brasileiros de Cardiologia. Vol. 87. Num. 6. 2006, p. 264-270.

62-Zhao, Y.; Vanhoutte, P.M.; Leung, W.S. Vascular nitric oxid: Beyond e NOS. Journal of Pharmacological Sciences. Tokyo. Vol. 129. Num. 2. 2015. p. 83-94.

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