4-2026

# Beetroot juice and vitamin C co-supplementation enhances anaerobic performance and reduces post-exercise glycemia in wrestlers: a randomized, double-blind, placebo-controlled crossover trial

Maedeh Nojoumi

Ali Jafari

Alireza Hosseini Kakhiki

Ali Jafarzadeh Esfehani

Hossein Rafiei

*See next page for additional authors*

Authors
Maedeh Nojoumi, Ali Jafari, Alireza Hosseini Kakhiki, Ali Jafarzadeh Esfehani, Hossein Rafiei, Chad Kerksick, Oluwatoyosi Owoeye, and Reza Rezvani

Nutrition & Metabolism

https://doi.org/10.1186/s12986-026-01103-6

Article in Press

# Beetroot juice and vitamin C co-supplementation enhances anaerobic performance and reduces post-exercise glycemia in wrestlers: a randomized, double-blind, placebo-controlled crossover trial

Received: 28 November 2025

Accepted: 3 March 2026

Published online: 17 April 2026

**Cite this article as: Nojoumi M., Jafari A., Kakhki A.H. *et al.* Beetroot juice and vitamin C co-supplementation enhances anaerobic performance and reduces post-exercise glycemia in wrestlers: a randomized, double-blind, placebo-controlled crossover trial. *Nutr Metab (Lond)* (2026). https://doi.org/10.1186/s12986-026-01103-6**

**Maedeh Nojoumi, Ali Jafari, Alireza Hosseini Kakhki, Ali Jafarzadeh Esfehani, Hossein Rafiei, Chad Kerksick, Oluwatoyosi Owoeye & Reza Rezvani**

# Beetroot Juice and Vitamin C Co-Supplementation Enhances Anaerobic Performance and Reduces Post-Exercise Glycemia in Wrestlers: A Randomized, Double-Blind, Placebo-Controlled Crossover Trial

Maedeh Nojoumi[1], Ali Jafari[2], Alireza Hosseini Kakhki[3], Ali Jafarzadeh Esfehani[1], Hossein Rafiei[4], Chad Kerksick[5], Oluwatoyosi Owoeye[6] and Reza Rezvani[1*]

[1] Department of Nutrition, Faculty of Medicine, Mashhad University of Medical Sciences, Mashhad, Iran.

[2] Student Research Committee, Department of Community Nutrition, Faculty of Nutrition Sciences and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[3] Department of Sports Physiology, Faculty of Sports Sciences, Ferdowsi University of Mashhad, Mashhad, Iran.

[4]Department of Nutrition and Dietetics, Doisy College of Health Sciences, Saint Louis University, St. Louis, MO, United States.

[5]Department of Exercise Science, Exercise and Performance Nutrition Laboratory, College of Science, Technology, and Health, Lindenwood University, St. Charles, MO, United States.

[6]Department of Physical Therapy and Athletic Training, Doisy College of Health Sciences, Saint Louis University, St. Louis, MO, United States.



*Corresponding author:
**Reza Rezvani MD, Ph.D., PDF**
**Assistant Professor of Clinical Nutrition**
Head, Deputy of Education of Nutrition Department
School of Medicine, Mashhad University of Medical Sciences.
Azadi Square, Campus of University, Mashhad, Iran
Postal Code: 9177948564

Emai address:

RezvaniR@mums.ac.ir

Rerez1@ulaval.ca

Reza.Rezvani.rr@gmail.com

Word count (main text only): 3490

Figures: 2

Tables: 5

## Abstract

**Background**: Wrestling, characterized by high-intensity intermittent efforts, demands exceptional anaerobic power and recovery capacity. Nitrate-rich beetroot juice (BRJ), supplemented with vitamin C, has emerged as a potential ergogenic aid through increased nitric oxide bioavailability. However, limited data exists regarding its acute effects on anaerobic performance in combat sport athletes. This study investigated the acute effects of BRJ supplemented with vitamin C on upper- and lower-body anaerobic test performance and selected biochemical markers in collegiate wrestlers.

**Methods**: In a randomized, double-blind, placebo-controlled crossover trial, 28 collegiate male wrestlers (18–24 years) consumed a single 250-ml BRJ drink (8.4 mmol nitrate + 90 mg vitamin C) or an isocaloric nitrate-free placebo three hours prior to testing, with a 14-day washout between conditions. Participants performed sequential 30-second upper- and lower-body Wingate anaerobic test (WAnTs) separated by 90 seconds. Venous blood was collected pre-test, immediately post-test, and 24 hours post-test and was analyzed for blood glucose, creatine kinase (CK), and lactate dehydrogenase (LDH).

**Results**: 24 completed the study. BRJ+vitamin C significantly increased upper-body WAnT peak power (419±98 W vs. 403±103 W, $P<0.001$) and lower-body WAnT mean power (390±89 W vs. 376±89 W, $P=0.002$) compared with placebo. Post-exercise blood glucose was significantly lower in the BRJ + vitamin C group (96.3±19.2 mg/dl vs. 112.5±20.4 mg/dl, $P<0.001$). No significant differences were observed for CK ($P = 0.59$) or LDH ($P = 0.27$) at any measured time point.

**Conclusion**: Acute BRJ + vitamin C supplementation improved anaerobic capacity and lowered post-exercise blood glucose in collegiate wrestlers, offering a potential ergogenic strategy for combat sports. Further studies with larger, diverse populations and chronic supplementation are needed to confirm and extend these findings.



**Trial registration and date:** Iranian Registry of Clinical Trials (IRCT20240407061440N1); registration date: June 7, 2024.

**Keywords:** Beetroot Juice, Vitamin C, Wingate Anaerobic Test, Anaerobic Capacity, Glycemic Control, Wrestling

# 1. Introduction

Wrestling is an Olympic sport characterized by high-intensity, intermittent efforts that demands exceptional anaerobic power, muscular strength, and endurance across upper and lower body musculature (1, 2). With up to 90% of energy derived from anaerobic glycolysis during matches, wrestlers rely heavily on strategies to optimize power output and recovery (3, 4). Athletes in competitive sports like wrestling increasingly utilize dietary supplements to enhance physical and psychological capabilities (5, 6).



Dietary supplements, as defined by the International Olympic Committee, are targeted nutritional compounds consumed to achieve specific health or performance benefits (6). Among these, beetroot (*Beta vulgaris rubra*), rich in nitrate $NO_3^-$ and bioactive phytochemicals such as betalains, flavonoids, and polyphenols (7), has recently been recognized as a potent ergogenic aid capable of enhancing exercise performance and alleviating exercise-related tissue stress (8-12). Beetroot naturally contains high levels of inorganic $NO_3^-$, typically 1–10 mmol/kg fresh weight in raw beets (varying by cultivar and conditions), while concentrated beetroot juice products commonly deliver 5–8 mmol nitrate per acute dose for ergogenic purposes (13, 14).

$NO3^-$ from beetroot juice (BRJ) enhances nitric oxide (NO) bioavailability through its reduction to nitrite ($NO_2^-$) and subsequently NO, particularly under hypoxic and acidic conditions, which are prevalent during high-intensity exercise (15-18). This process promotes vasodilation, improves blood flow, enhances muscle efficiency, and reduces the oxygen cost of exercise, potentially benefiting anaerobic performance in sports like wrestling (17-21). Furthermore, emerging evidence suggests that increased

NO bioavailability may also improve glucose uptake in skeletal muscle, independent of insulin and muscle contraction pathways, by stimulating GLUT4 translocation and glucose transport (22, 23). This mechanism could help attenuate exercise-induced hyperglycemia, which commonly occurs during high-intensity anaerobic efforts due to catecholamine-mediated hepatic glucose output and reduced peripheral glucose disposal. Additionally, BRJ's antioxidant properties, driven by betalains, may reduce exercise-induced muscle damage and inflammation, as evidenced by decreased serum levels of creatine kinase (CK) and lactate dehydrogenase (LDH) (12, 24).

Vitamin C, a potent water-soluble antioxidant, enhances NO production by neutralizing reactive oxygen species (ROS) and facilitating $NO_3^-$ reduction to NO under hypoxic and acidic conditions (25-27). Vitamin C acts as a cofactor in deoxyhemoglobin-mediated reactions and acidified $NO_3^-$ conversion (25). By scavenging exercise-induced ROS, vitamin C may preserve NO bioavailability and further support NO-mediated glucose uptake in muscle, potentially providing a synergistic effect with BRJ in mitigating post-exercise hyperglycemia (28).



Therefore, it can be hypothesized that vitamin C may amplify the ergogenic benefits of nitrate-rich BRJ not only in improving anaerobic performance and recovery, but also in attenuating exercise-induced hyperglycemia, which may otherwise contribute to fatigue, osmotic stress, and delayed recovery in wrestlers. However, the combined effects of dietary nitrate and vitamin C supplementation, particularly in combat sports, remain underexplored, highlighting a critical gap in the literature (25, 29, 30). The rationale underlying the selection of this supplement, along with its design as a performance-enhancing strategy for wrestlers, is illustrated in Figure 1.

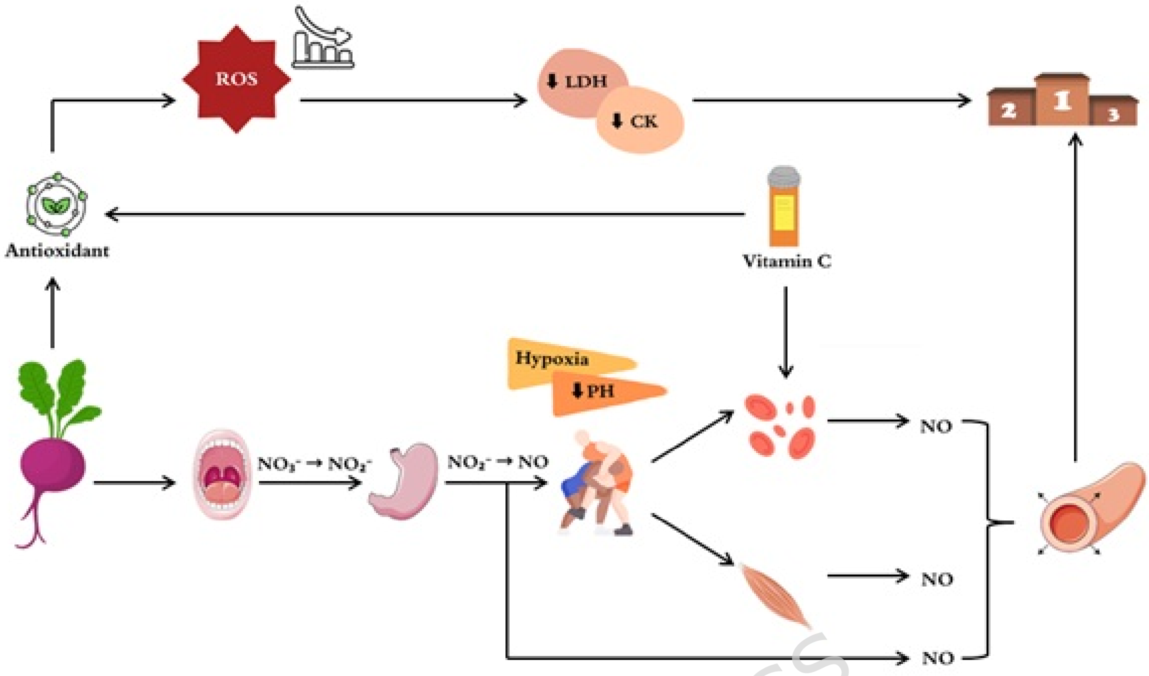


**Figure 1. Hypothesized Mechanism of Anaerobic Performance Enhancement from Combined Beetroot Juice and Vitamin C Supplementation**



Wrestling stands out as a discipline heavily dependent on anaerobic energy systems, characterized by intense exertions spanning 6 to 60 seconds, predominantly fueled by glycolytic processes (31). Although the acute administration of beetroot supplements has been thoroughly investigated for its influence on upper and lower body performance in the Wingate Anaerobic Test (WAnT), with separate evaluations conducted for upper-body and lower-body protocols (32-35), a combined alternating protocol has not yet been implemented, leaving significant gaps in this area (36). Previous studies have predominantly concentrated on successive trials within a single body region, neglecting the dynamic, sequential activation of both upper and lower extremities that is emblematic of combat sports (37-39).

This study sought to address a key gap in the literature by investigating the acute effects of a single dose of beetroot juice combined with vitamin C on upper and lower body anaerobic performance and selected biochemical markers in collegiate wrestlers. To enhance ecological validity, a novel sequential WAnT protocol involving consecutive upper and lower body efforts was employed to closely replicate the multifaceted physiological demands characteristic of competitive wrestling. We hypothesized that this combination would improve anaerobic performance in wrestlers, attenuate exercise-induced hyperglycemia, and reduce muscle damage markers (6, 26, 27, 40).

# 2. Materials and Methods

## 2.1. Study Design

A randomized, double-blind, placebo-controlled, crossover trial was conducted from June to July 2024 at Ferdowsi University's Faculty of Sport Sciences, Iran. The study was approved by the Ethics Committee of Mashhad University of Medical Sciences (IR.MUMS.MEDICAL.REC.1403.011) and registered with the Iranian Registry of Clinical Trials (IRCT20240407061440N1). All procedures adhered to the Declaration of Helsinki.



## 2.2. Participants

Twenty-eight collegiate male wrestlers were recruited via coaches at Ferdowsi University of Mashhad, Iran. Inclusion criteria included age 18–24 years, non-elite status, at least 2 years of wrestling experience, prior WAnT experience, and adherence to the study protocol. Exclusion criteria encompassed caffeine consumption within 24 hours prior to testing, use of nitrate-containing medications or supplements within the past six months, herbal medication use, presence of any cardiovascular, pulmonary, metabolic, neurological, or orthopedic conditions limiting cycle ergometry, recent acute cardiac events, beetroot allergies, use of oral antiseptics within the past four weeks, addiction, alcoholism, or intense exercise within 72 hours prior to testing. Eligibility was assessed through medical history questionnaires and physical examinations conducted by a study physician. Participants were withdrawn for acute illness, adverse effects impacting quality of life, or unwillingness to continue.

## 2.3. Randomization and Blinding

Participants were randomized to receive BRJ drink (8.4 mmol $NO_3^-$ plus 90 mg vitamin C) or an isocaloric placebo in random order, with a 14-day washout period to eliminate carryover effects (41). Randomization was performed using a web-based tool (www.sealedenvelope.com), with allocation concealed in numbered, opaque, sealed envelopes managed by an independent staff member. Blinding was maintained for participants, assessors (conducting WAnT, blood sampling, and RPE questionnaires), and analysts. Intervention and placebo drinks, matched for appearance and taste, were prepared and labeled by an independent staff member. Allocation details were inaccessible until data collection was complete.



## 2.4. Intervention and Placebo

The intervention was a 250-ml BRJ drink containing 8.4 mmol $NO_3^-$ (from 56 g freeze-dried beetroot powder) and 90 mg vitamin C, with 0.25 g/ml added sugar. The nitrate dose was based on evidence indicating performance benefits with 5–14.9 mmol $NO_3^-$ consumed 2–3 hours pre-exercise (18, 42). The placebo drink was isocaloric to the intervention drink and contained 0.4 mg/ml citric acid, 0.2 mg/ml food coloring, with 0.25 g/ml added sugar. Both the intervention and placebo drinks were administered three hours prior to Wingate tests to maximize plasma levels of $NO_3^-$ (41), vitamin C (43), and polyphenols (44), corresponding to peak bioavailability.

Beetroot was juiced and freeze-dried to preserve nutrients and minimize contamination (45-47). The powder was tested for heavy metals and $NO_3^-$ content, confirming safety per FAO/WHO standards (48, 49). High-nitrate foods were avoided during the washout period in both conditions and compliance to this was confirmed throughout the study protocol.

## 2.5. Procedures

The study involved three visits (second and third visits separated by two weeks). At the first visit, participants completed medical history questionnaires, underwent eligibility screening, and were familiarized with Monark cycle ergometers (Ergomedic 891E for upper body, 894E for lower body; Vansbro, Sweden). Anthropometric (height via stadiometer, body composition via InBody 720 Bioelectrical Impedance Analyzer) and baseline assessments (72-hour food record, International Physical Activity Questionnaire) were performed (50, 51).



On testing days, participants consumed either the supplement drink or a placebo within 10 minutes and rested quietly in the laboratory for three hours before beginning a warm-up. Warm-up included 5 min of cycling at 50 W with three short sprints, 5 min of rest, and ~3 min of dynamic stretching immediately before the Wingate tests. From there, each participant performed a 30-second upper-body WAnT and a 30-second lower-body WAnT in a sequential fashion with a 60-second break between the tests. This specific order was followed for all participants for all testing sessions. Prior research indicates that a 30-second lower-body WAnT is unaffected by a preceding 30-second upper-body WAnT, whereas upper-body performance significantly declines following a lower-body WAnT (38). Despite elevated blood lactate levels, subsequent lower-body peak and mean power remain unchanged (38). This supports the use of sequential WAnT protocols targeting different body regions to assess integrated anaerobic performance. Further, this approach strengthens the face validity of our protocol due to dynamic demands of wrestling involving both the upper-body and lower musculature. Upper-body WAnT was assessed using a modified Monark ergometer (fixed table, seated position, elbows near full extension). Lower-body WAnT was assessed using a standard ergometer (seat adjusted for ~5° knee flexion). Resistance was set to 5% and 7.5% of body weight for upper body and lower body WAnT tests, respectively (52, 53). Power output (peak power, mean power, minimum power, time to peak power, fatigue index) was recorded using Wingate (version 1.0.7) software. Blood samples (10 ml, brachial vein) were collected pre-test (3 hours post-supplementation), immediately post-WAnT, and 24 hours post-WAnT. Blood samples (10 ml, brachial vein) were collected pre-test (3 hours post-supplementation), immediately post-test, and 24 hours post-test. Samples were centrifuged at 3000 rpm for 10 minutes at 4°C to separate serum. Serum glucose, CK, and lactate LDH were analysed as follows:



Serum glucose was measured in triplicate using a colorimetric enzymatic assay (GOD-PAP) with commercial reagents from the Glucose Enzymatic Kit (BioRexFars Innovative Diagnostics, Iran). The assay was conducted at 546 nm, 37°C, with a 1 cm cuvette against a reagent blank.

Serum CK was measured in triplicate using an enzymatic assay (IFCC method) with commercial reagents from the CK-NAC Kit (BioRexFars Innovative Diagnostics, Iran), including reagent R1 (Imidazole buffer pH 6.7, Glucose 20 mmol/l, Mg-acetate 10 mmol/l, EDTA 2 mmol/l) and reagent R2 (ADP 2 mmol/l, NADP 2 mmol/l, AMP 3 mmol/l, Hexokinase ≤ 2.5 U/ml, Diadenosine pentaphosphate 5 µmol/l, G6PDH ≤ 1.5 U/ml, N-Acetyl Cysteine 20 mmol/l, Creatine phosphate 30 mmol/l). The assay was conducted at 340 nm, 37°C, with a 1 cm cuvette against a reagent blank.

Serum LDH was measured in triplicate using an enzymatic assay (IFCC method) with commercial reagents from the LDH Kit (BioRexFars Innovative Diagnostics, Iran), including R1 (Tris buffer pH 7.5 50 mmol/l, Pyruvate 0.6 mmol/l) and R2 (NADH 0.18 mmol/l). The assay was conducted at 340 nm, 37°C, with a 1 cm cuvette against a reagent blank. Adverse effects were monitored daily.

Considering the nitrate half-life of roughly 5 to 8 hours, a 14-day washout interval was deemed adequate to substantially diminish any lingering influences from prior nitrate intake (54). By employing a crossover design where participants acted as their own controls, testing sessions were scheduled at identical times of day across both conditions to minimize circadian variability.

## 2.6. Control of confounders

To minimize the influence of confounding factors, diet, physical activity, and circadian rhythms were rigorously controlled. Participants were provided with standardized dietary guidelines and instructed to follow a consistent low-nitrate diet for 72 hours prior to each testing session, avoiding foods high in $NO_3^-$ (e.g., leafy greens, beets, and processed meats). Intervention compliance was monitored through 72-hour food records collected at the first visit and reviewed by a study nutritionist before each session. Participants were also instructed to refrain from intense physical activity for 72 hours prior to testing, and their baseline physical activity levels were assessed using the International Physical Activity Questionnaire (IPAQ) to ensure consistency across sessions (50). To minimize potential influences of daily biological fluctuations, participants completed their assessments at a consistent time window (11:00–14:00) across all visits. Additionally, a washout interval of at least 14 days was implemented to reduce any residual or carryover effects between testing sessions.



## 2.7. Sample Size

Sample size was calculated based on mean power data from a previous study by Williams et al. (9) (placebo: 508.14 ± 117.55 W; BRJ: 607.36 ± 112.28 W). The required sample size
was calculated to be 22 participants for a crossover design considering 95% confidence and 80%
power using the following equation:

$$n = \frac{(k \times \delta_1^2 + \delta_2^2)(Z_{1-\alpha/2} + Z_{1-\beta})^2}{\Delta^2}$$

In the above equation n is the sample size in each group, k is the ratio of the groups, which is one
in this study, $\delta$ is the standard deviation in each group, $\Delta$ is the difference of group means, $Z_{1-\alpha/2}$ is considered 1.96 for 95% confidence interval, and $Z_{1-\beta}$ is the power of the study. To mitigate the risk of attrition and to secure completion of all planned study visits, the study initially recruited 28 participants.



## Statistical Analysis

Data were analyzed using SPSS v26. Normality was assessed via Shapiro-Wilk test. Independent t-test was used for the comparison of normally distributed variables and Mann-Whitney test was used for the comparison of non-normally distributed variables. In order to assess the carryover effect, univariate General Linear Model (GLM) was used independently for each variable with each outcome variable as dependent variable and treatment and sequence of interventions as fixed factors. The carryover effect was defined as the treatment-sequence (carryover) effects in the model. All texts were performed two-sided and the statistical significance level was set at $p < 0.05$.

# 3. Results

## 3.1. Participant Characteristics

Of 28 enrolled collegiate male wrestlers, 24 (85.7%) completed the study; four withdrew due to unwillingness to continue after the first session. The flow of participants is presented in Figure 2, following CONSORT guidelines.

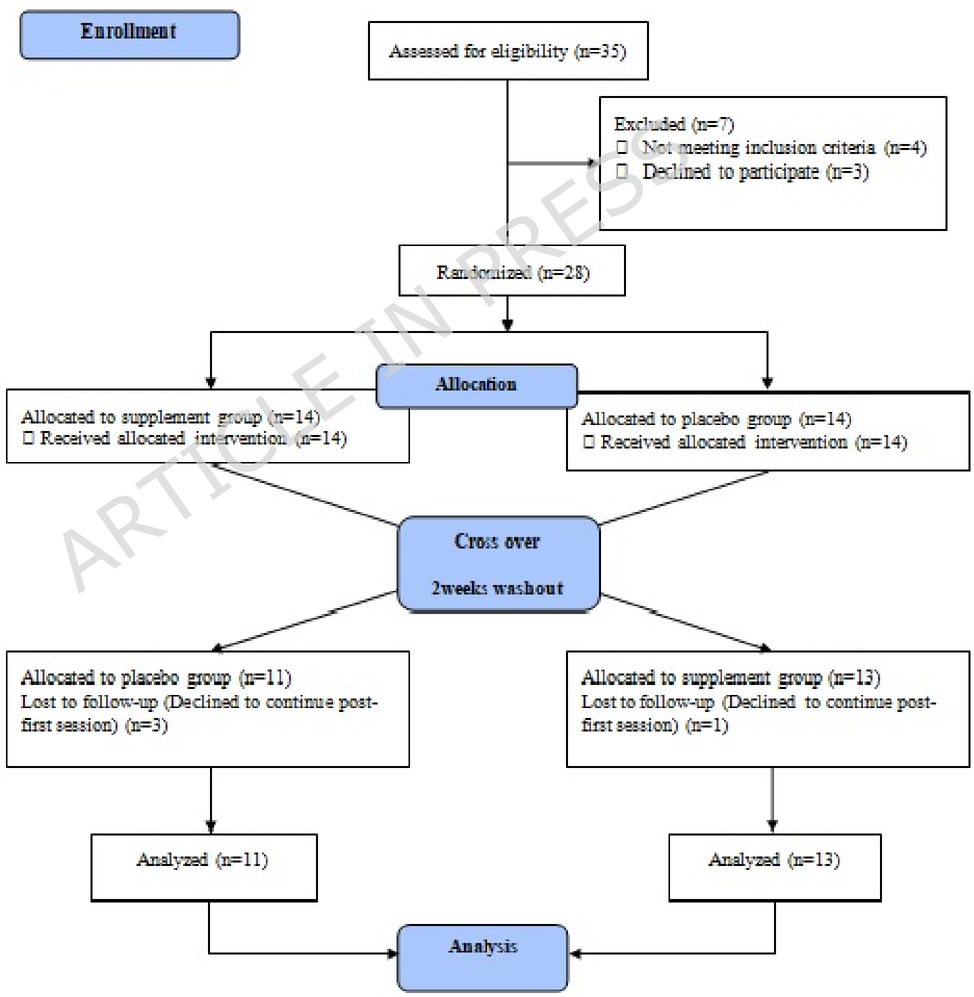


**Figure 2. CONSORT 2010 Flow Diagram for a Crossover Trial**

Baseline characteristics are summarized in Table 1.

**Table 1 | Demographic and Anthropometric Characteristics**

| **Variable** | **Value** |
|---|---|
| Age (years) | 21.0 ± 3.2 |
| Weight (kg) | 67.9 ± 11.8 |
| Height (cm) | 172.2 ± 6.0 |
| BMI (kg/m²) | 22.7 ± 3.0 |

*Data are means ± SD. SD = standard deviation; BMI = body mass index.*

## 3.2. Upper-Body Wingate Anaerobic Test (WAnT) Outcomes

The BRJ+vitamin C group exhibited significantly higher peak power (419 ± 98 W vs. 403 ± 103 W, $P < 0.001$) and peak power per body weight (6.2 ± 0.8 W/kg vs. 5.9 ± 0.8 W/kg, $P < 0.001$) compared to the placebo group in the upper-body WAnT (Table 2). Although mean power was higher in the BRJ+vitamin C group (260 ± 72 W vs. 246 ± 75 W, $P = 0.099$), this difference did not reach statistical significance. No significant differences were observed for minimum power, minimum power per body weight, mean power per body weight, time to peak power, or fatigue index (all $P \geq 0.05$). No significant intervention-by-time interactions or carryover effects were detected ($P > 0.05$).



**Table 2 | Upper-Body Wingate Anaerobic Test Outcomes (3 Hours Post-Supplementation)**

| **Variable** | **BRJ+VitC** | **Placebo** | ***P*-value** |
|---|---|---|---|
| Peak Power (W)* | 419 ± 98 | 403 ± 103 | <0.001 |
| Peak Power (W/kg)* | 6.2 ± 0.8 | 5.9 ± 0.8 | <0.001 |
| Mean Power (W) | 260 ± 72 | 246 ± 75 | 0.099 |
| Mean Power (W/kg) | 3.7 ± 0.8 | 3.6 ± 0.8 | 0.178 |

| | | | |
|---|---|---|---|
| Minimum Power (W) | 42.7 ± 118.2 | -81.2 ± 121.2 | 0.182 |
| Minimum Power (W/kg) | -0.68 ± 1.77 | -1.28 ± 1.73 | 0.165 |
| Time to Peak Power (s) | 10.3 ± 3.3 | 9.8 ± 3.5 | 0.369 |
| Fatigue Index | 113 ± 31 | 124 ± 30 | 0.158 |

*BRJ: beetroot juice; *: significant difference for placebo vs. BRJ+Vit C ($p < 0.05$); Data are means ± SD.*

### 3.3. Lower-Body Wingate Anaerobic Test (WAnT) Outcomes

In the lower-body WAnT, the BRJ+vitamin C group showed significantly higher mean power (390 ± 89 W vs. 376 ± 89 W, P = 0.002) and mean power per body weight (5.8 ± 0.9 W/kg vs. 5.3 ± 0.8 W/kg, P = 0.001) compared to placebo (Table 3). No significant differences were observed for peak power, peak power per body weight, minimum power, minimum power per body weight, time to peak power, or fatigue index (all P ≥ 0.05). No significant intervention-by-time interactions or carryover effects were detected (P > 0.05).



**Table 3 | Lower-Body Wingate Anaerobic Test Outcomes (3 Hours Post-Supplementation)**

| **Variable** | **BRJ+VitC** | **Placebo** | ***P*-value** |
|---|---|---|---|
| Peak Power (W) | 516 ± 132 | 513 ± 126 | 0.752 |
| Peak Power (W/kg) | 7.4 ± 0.9 | 7.6 ± 1.0 | 0.320 |
| Mean Power (W)* | 390 ± 89 | 376 ± 89 | 0.002 |
| Mean Power (W/kg)* | 5.8 ± 0.9 | 5.3 ± 0.8 | 0.001 |
| Minimum Power (W) | 199 ± 67 | 205 ± 49 | 0.625 |
| Minimum Power (W/kg) | 2.9 ± 1.0 | 3.1 ± 0.7 | 0.493 |

| | | | |
|---|---|---|---|
| Time to Peak Power (s) | 5.3 ± 2.6 | 5.6 ± 2.2 | 0.690 |
| Fatigue Index | 60.4 ± 13.2 | 58.8 ± 9.1 | 0.494 |

*BRJ: beetroot juice; *: significant difference for placebo vs. BRJ+Vit C (p < 0.05); Data are means ± SD.*

### 3.4. Biochemical Markers

Serum glucose levels were significantly lower in the BRJ+vitamin C group compared to placebo both pre-test (72.0 ± 6.7 mg/dl vs. 82.6 ± 9.0 mg/dl, P < 0.001) and post-test (96.3 ± 19.2 mg/dl vs. 112.5 ± 20.4 mg/dl, P < 0.001) (Table 4). No significant differences were observed for CK or LDH levels in pre-test, post-test, or 24 hours post-test (P ≥ 0.05). No intervention-by-time interactions or carryover effects were detected (P > 0.05).



**Table 4 | Biochemical Marker Outcomes**

| Variable | Time Point | BRJ+VitC | Placebo | *P*-value |
|---|---|---|---|---|
| CK (U/L) | Pre-Test | 210 ± 122 | 219 ± 168 | 0.798 |
| | Post-Test | 290 ± 199 | 271 ± 192 | 0.729 |
| | Difference (post-pre) | 37.5 (9.8-124.8)* | 21 (11.5-54.3)* | 0.392 |
| | 24 h Post-Test | 351 ± 222 | 321 ± 211 | 0.596 |
| LDH (U/L) | Pre-Test | 335 ± 73 | 354 ± 98 | 0.278 |
| | Post-Test | 405 ± 75 | 416 ± 90 | 0.535 |
| | Difference (post-pre) | 69.8 ±51.5 | 48 (23.75-72.75)* | 0.370 |
| | 24 h Post-Test | 454 ± 99 | 467 ± 98 | 0.536 |
| BG (mg/dl)* | Pre-Test | 72.1 ± 6.7 | 82.6 ± 9.0 | <0.001 |

| | | | | |
|---|---|---|---|---|
| | Post-Test | 96.3 ± 19.2 | 112.5 ± 20.4 | <0.001 |
| | Difference (post-pre) | 24.2 ±18.2 | 29.8 ± 18.4 | 0.292 |

*BRJ: Beetroot Juice; CK: Creatine Kinase; LDH: Lactate dehydrogenase; BG: Blood Glucose; BG not measured at 24 h post-test; *: significant difference for placebo vs. BRJ+Vit C (p < 0.05);*

** Median and interquartile range was used due to non-normal distribution of data*

*All tests were independent t-test except for comparison of the difference in CK and LDH, for which the Mann-Whitney test was used.*

## 3.5. Carryover effect

The effect of treatment-sequence (carryover) is shown in Table 5. Significant carryover effect was seen only in upper body time to peak (p=0.042) and lower body minimum power (p=0.018).



**Table 5 | Effect of treatment, sequence, and treatment-sequence (carryover)**

| | Variable | Treatment-sequence effect (carryover) |
|---|---|---|
| Upper body | Peak Power (W) | 0.071 |
| | Peak Power (W/kg) | 0.113 |
| | Mean Power (W) | 0.123 |
| | Mean Power (W/kg) | 0.518 |
| | Minimum Power (W) | 0.153 |
| | Minimum Power (W/kg) | 0.146 |
| | Time to Peak Power (s) | 0.042* |

| | | |
|---|---|---|
| Lower body | Peak Power (W) | 0.187 |
| | Peak Power (W/kg) | 0.484 |
| | Mean Power (W) | 0.308 |
| | Mean Power (W/kg) | 0.910 |
| | Minimum Power (W) | 0.018* |
| | Minimum Power (W/kg) | 0.070 |
| | Time to Peak Power (s) | 0.404 |
| CK | Pre-Test | 0.598 |
| | Post-Test | 0.446 |
| | 24 h Post-Test | 0.591 |
| LDH | Pre-Test | 0.750 |
| | Post-Test | 0.467 |
| | 24 h Post-Test | 0.586 |
| BG | Pre-Test | 0.593 |
| | Post-Test | 0.172 |

*CK: Creatine Kinase; LDH: Lactate dehydrogenase; BG: Blood Glucose; BG not measured at 24 h post-test. Univariate general linear model was used to assess the effects.*



# 4. Discussion

In this randomized, double-blind, placebo-controlled crossover trial, an acute dose of BRJ enriched with vitamin C (BRJ+VitC, 8.4 mmol nitrate, 90 mg vitamin C) produced modest but statistically significant improvements in selected measures of anaerobic performance, specifically upper-body WAnT peak power and lower-body WAnT mean power in collegiate male wrestlers. Additionally, BRJ+VitC attenuated the rise in post-exercise serum glucose. No treatment effect was observed for the muscle-damage biomarkers CK or lactate LDH. Collectively, these findings highlight the ergogenic potential of combined nitrate and vitamin C supplementation in combat sports, particularly wrestling, where sequential high-intensity efforts are critical.

The improvements in upper-body peak power and lower-body mean power align with prior studies demonstrating that dietary nitrate can increase peak and mean power during short, high-intensity efforts (20, 55-57). For example, Domínguez et al. (55) reported increased peak and mean power in the WAnT with 5.6 mmol $NO_3^-$ from BRJ and Hashemi Fard et al. (57) observed enhanced anaerobic power in karate athletes. Our results extend this literature by showing benefits in a repeated, sequential upper-then-lower body WAnT protocol designed to better mimic the mixed demands of wrestling.

In this crossover trial, BRJ significantly increased peak anaerobic power in the upper-body Wingate test but not in the lower-body test. Mechanistically, $NO_3^-$ from BRJ is reduced to $NO_2^-$ and NO via enterosalivary and tissue pathways, particularly under hypoxic and acidic conditions typical of maximal anaerobic bouts. NO can acutely improve muscle contractile function, calcium handling in type II fibers, and local blood flow effects that plausibly contribute to improved peak and mean power (58-60). Vitamin C may possibly augment these effects by (1) attenuating oxidative inactivation of NO and (2) supporting reductive pathways that favor $NO_2^- \rightarrow NO$ conversion, potentially enhancing NO bioavailability. BRJ also reduces ATP demand and phosphocreatine depletion, supporting sustained high-intensity performance (61, 62). The clearer response in upper-body peak power compared to lower-body peak power is consistent with heterogeneous responses across muscle groups reported in the literature, potentially reflecting differences in muscle mass, motor unit recruitment patterns, or local perfusion (63-65). Also a lower $NO_3^-$ dose compared to studies reporting ergogenic effects (11.2 mmol) (66, 67). These findings highlight

BRJ's potential to enhance upper-body performance in wrestling. The lack of effect on minimum power, time to peak power, and fatigue index may reflect the specific muscle groups involved or the acute dosing strategy, as chronic supplementation often yields broader benefits (10, 42).

Although some studies suggest BRJ supplementation may reduce exercise-induced CK elevations (24, 68), most studies, including ours, indicate BRJ fails to mitigate CK and LDH levels (69-72). Similarly, cherry and pomegranate juices show limited efficacy in altering CK and LDH levels (73, 74), suggesting antioxidant-rich foods may not reduce muscle damage. CK in particular is highly variable between individuals (75) and influenced by exercise modality, muscle mass, and sampling time; a single acute dose is unlikely to meaningfully alter these markers. Chronic supplementation or different timing may be necessary to observe consistent effects on biochemical indices of muscle damage



The significant reduction in serum glucose post-exercise suggests that BRJ+VitC improves glycemic control during high-intensity exercise. High-intensity anaerobic exercise, such as the WAnT, typically elevates plasma glucose due to catecholamine-induced hepatic glucose output, followed by post-exercise hypoglycemia as counter-regulatory hormones decline (76-85). BRJ, rich in nitrate, and vitamin C, a potent antioxidant, are studied for their potential to influence glucose regulation, especially after high-intensity exercise like the WAnT (28, 86, 87). The reduction in post-exercise serum glucose observed in our trial could reflect increased insulin-independent glucose uptake via NO-mediated stimulation of GLUT4 translocation in skeletal muscle, a mechanism independent of insulin and contraction pathways (22, 23). Vitamin C likely contributes synergistically by neutralizing exercise-induced reactive oxygen species (ROS), thereby preserving NO bioavailability and supporting glucose disposal amid oxidative stress (28). These complementary actions, NO promotion of

GLUT4 translocation and ROS scavenging, may collectively attenuate the glycemic excursion, although direct measures of insulin, lactate, $NO_3^-/NO_2^-$, or muscle GLUT4 were not collected here and therefore mechanistic inferences remain speculative (29, 88-90).

The effects of BRJ on post-exercise glucose levels vary across studies. In contrast to Vasconcellos et al. (91), who found no significant reduction in post-exercise glucose with BRJ alone and greater reductions in the placebo group, our study observed improved glycemic control with BRJ supplemented with vitamin C, likely due to the synergistic effects of vitamin C. These effects may be attributed to vitamin C's antioxidant properties, which reduce oxidative stress and enhance insulin-independent glucose uptake, as well as its role in promoting NO production, which improves muscle perfusion and glucose metabolism (92-94). Furthermore, mitigating post-exercise hyperglycemia may positively influence anaerobic performance in wrestlers (95). Elevated blood glucose excursions can lead to osmotic stress, potential dehydration (96), exacerbated metabolic acidosis (97), and increased perceived fatigue, which may impair recovery between intermittent high-intensity efforts and reduce power output in subsequent bouts. By reducing these glycemic spikes, BRJ + VitC may decrease fatigue accumulation, enhance recovery kinetics, and support sustained explosive performance, particularly relevant in combat sports with repeated anaerobic demands (98). Variability in glucose responses may also arise from differences in exercise intensity and participant fitness levels (40).



Several studies have investigated the ergogenic effects of BRJ monotherapy (without vitamin C) on anaerobic performance, predominantly using Wingate anaerobic tests or high-intensity protocols in trained or recreationally active individuals. Acute BRJ supplementation has been shown to modestly improve peak power by approximately 3–5% and mean power by 3–6%, with reductions in time to peak power in some cases (99-101). In combat sports athletes, including wrestlers, BRJ alone has enhanced isokinetic strength and explosive power, though effects on overall anaerobic power output vary (102-104).

In the present study, BRJ + vitamin C co-supplementation significantly improved upper-body peak power by approximately 4.0–5.1% and lower-body mean power by 3.7–9.4%, alongside a marked attenuation of post-exercise blood glucose elevation. These improvements in peak and mean power align with or modestly exceed the typical range reported in BRJ-only studies, particularly in mean power for lower-body efforts and in the context of wrestlers' high anaerobic demands. Notably, the substantial reduction in post-exercise glycemia is less commonly emphasized in BRJ monotherapy trials and may reflect an additive antioxidant contribution from vitamin C, potentially mitigating oxidative stress and supporting glucose uptake via preserved NO bioavailability.

However, direct head-to-head comparisons are limited, and co-supplementation studies remain scarce. A recent systematic review on BRJ co-supplementation highlighted that additive benefits often depend on chronic duration rather than acute dosing, though evidence for vitamin C specifically is sparse (104).

Compared to other supplements commonly used in wrestlers (Prieto Martínez et al., 2025) (105), our acute BRJ + VitC co-supplementation produced modest but significant improvements in anaerobic performance. Creatine monohydrate generally shows stronger effects on anaerobic power, strength and recovery in wrestlers, while sodium citrate aids body mass regain after weight cutting, and spirulina or BCAA yield mixed or weaker results on anaerobic metrics. Our protocol uniquely attenuated post-exercise hyperglycemia, a benefit rarely reported for other supplements, which may help reduce fatigue in repeated high-intensity bouts. Overall, BRJ + VitC offers a practical acute option with additive metabolic advantages, though direct comparisons and larger studies are needed.

## Strengths and limitations

This study was the first to examine the combined effects of BRJ+VitC on sequential upper- and lower-body WAnT performance in collegiate wrestlers, addressing a critical gap in combat sport research (10). Strengths include the crossover design, which minimized inter-subject variability, the use of a validated WAnT protocol on friction-braked Monark ergometers (106, 107), a familiarization session to reduce learning effects (108), and rigorous control of confounders (diet, physical activity, circadian rhythms). The double-blind methodology and use of freeze-dried beetroot powder helped to ensure all bioactive compounds were preserved, which both worked to support the internal validity of our design. Comprehensive assessments of anaerobic power, biochemical markers and anthropometrics further strengthen the findings.



Limitations include the small sample size (n=24 completers), which may have limited the detection of smaller effects, particularly for CK and LDH. The exclusion of female and elite wrestlers restricts generalizability to these populations. The acute supplementation protocol may not reflect the potential benefits of chronic dosing, which could yield broader ergogenic effects (10, 35). Additionally, a significant carryover effect was observed for upper body time to peak power (P=0.042) and lower body minimum power (P=0.018), though this was limited to only two of the 14 performance variables assessed. The 14-day washout period, while typically sufficient, may not have fully eliminated residual effects in these parameters. A major limitation of this study is the lack of a BRJ-only control group, which precludes definitive attribution of benefits to vitamin C's independent or synergistic role. Thus, while the observed effects suggest potential additive ergogenic advantages of co-supplementation, particularly for anaerobic power and glycemic regulation in wrestlers, these findings remain speculative without appropriate controls. Future trials should include BRJ-only, vitamin C-only, and combined arms to elucidate mechanisms and synergies in combat sport athletes. These findings underscore the need for further research with extended washout periods or parallel designs to clarify the persistence of such effects. Also, the lack of serum $NO_3^-$, $NO_2^-$, or lactate measurements limits mechanistic insights into NO bioavailability and metabolic responses.

## Future directions

Future studies should investigate chronic BRJ+VitC supplementation to assess cumulative effects on performance and recovery. Including female and elite wrestlers would broaden applicability. Measuring serum nitrate, nitrite, and lactate levels could clarify mechanistic pathways. Additionally, assessing inflammatory markers (e.g., cytokines) could provide deeper insights into recovery dynamics. Given the absence of significant adverse effects beyond mild gastrointestinal discomfort, longer-term safety studies are warranted.



## 5. Conclusion

In conclusion, acute BRJ+VitC supplementation improved selected measures of anaerobic power and reduced post-exercise serum glucose in collegiate male wrestlers. However, baseline imbalances in glucose and evidence of carryover for specific outcomes temper inference. Future trials should include serum $NO_3^-$/$NO_2^-$ and insulin measures, pre-specified primary outcomes with adequate power, and design features (longer washout or parallel groups) to eliminate carryover. If these issues are addressed, the combined nitrate + vitamin C strategy is a promising nutritional approach for combat sports.

## Data Availability Statement

The data supporting this study's findings are available upon request from the corresponding author.

## Ethics Statement

The studies involving human participants were reviewed and approved by the Ethics Committee of Mashhad University of Medical Sciences (IR.MUMS.MEDICAL.REC.1403.011). The participants provided their written informed consent to participate in this study. The trial was registered at the Iranian Registry of Clinical Trials (IRCT20240407061440N1).



## Author Contributions

Conceptualization and Supervision, R.R.; formal analysis, A.J.E.; investigation, M.N. and A.H.Kh.; Writing original draft, M.N. and A.J.; Writing review, H.R., C.K and O.O.; writing review, and editing, M.N. and R.R. . All authors have read and agreed to the published version of the manuscript.

## Funding

This trial is funded by Mashhad University of Medical Sciences.

## Acknowledgments

The authors sincerely thank the Vice-Chancellor for Research at Mashhad University of Medical Sciences (IR.MUMS.MEDICAL.REC.1403.011) for providing laboratory facilities and resources essential for this study. We are deeply grateful to the young wrestlers whose enthusiastic participation and commitment were vital to the success of this research.

## Statement on the Use of Artificial Intelligence (AI)

We acknowledge that this essay was edited and its writing style refined with the help of ChatGPT (GPT-5, OpenAI's large-scale language generation model, used via the editGPT extension). The AI was not used to create the manuscript's content or references; it was employed solely to enhance the language. All AI-assisted text was carefully reviewed, edited, and rewritten by the authors, who assume full responsibility for the article's accuracy and substance.

## Conflict of Interest

The authors confirm no conflicts of interest.

## Abbreviations

BRJ: Beetroot juice

VitC: Vitamin C

WAnT: Wingate anaerobic test

CK: Creatine kinase

LDH: Lactate dehydrogenase

NO: Nitric oxide

$NO_3^-$: Nitrate

$NO_2^-$: Nitrite

ROS: Reactive oxygen species

CONSORT: Consolidated Standards of Reporting Trials

IPAQ: International Physical Activity Questionnaire

GLM: General linear model

IRCT: Iranian Registry of Clinical Trials

## 6. References

1. Yoon J. Physiological profiles of elite senior wrestlers. Sports Medicine. 2002;32:225-33.
2. Mirzaei B, Ghahremani Moghaddam M, Alizaee Yousef Abadi H. Analysis of energy systems in Greco-Roman and freestyle wrestlers who participated in the 2015 and 2016 world championships. International Journal of Wrestling Science. 2017;7(1-2):35-40.
3. Hübner-Wozniak E, Kosmol A, Lutoslawska G, Bem E. Anaerobic performance of arms and legs in male and female free style wrestlers. Journal of science and medicine in sport. 2004;7(4):473-80.
4. Karnincic H, Tocilj Z, Uljevic O, Erceg M. Lactate profile during Greco-Roman wrestling matchx. Journal of sports science & medicine. 2009;8(CSSI3):17.
5. Burke LM, Castell LM, Casa DJ, Close GL, Costa RJ, Desbrow B, et al. International association of athletics federations consensus statement 2019: nutrition for athletics. International journal of sport nutrition and exercise metabolism. 2019;29(2):73-84.
6. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, et al. IOC consensus statement: dietary supplements and the high-performance athlete. International journal of sport

nutrition and exercise metabolism. 2018;28(2):104-25.

7. Gokhale S, Lele S. Betalain content and antioxidant activity of B eta vulgaris: effect of hot air convective drying and storage. Journal of Food Processing and Preservation. 2014;38(1):585-90.

8. Hemmatinafar M, Zaremoayedi L, Koushkie Jahromi M, Alvarez-Alvarado S, Wong A, Niknam A, et al. Effect of Beetroot Juice Supplementation on Muscle Soreness and Performance Recovery after Exercise-Induced Muscle Damage in Female Volleyball Players. Nutrients. 2023;15(17):3763.

9. Williams TD, Martin MP, Mintz JA, Rogers RR, Ballmann CG. Effect of acute beetroot juice supplementation on bench press power, velocity, and repetition volume. The Journal of Strength & Conditioning Research. 2020;34(4):924-8.

10. Delleli S, Ouergui I, Messaoudi H, Trabelsi K, Glenn JM, Ammar A, et al. Does Beetroot Supplementation Improve Performance in Combat Sports Athletes? A Systematic Review of Randomized Controlled Trials. Nutrients. 2023;15(2).

11. Rojano-Ortega D, Pena Amaro J, Berral-Aguilar AJ, Berral-De la Rosa FJ. Effects of beetroot supplementation on recovery after exercise-induced muscle damage: A systematic review. Sports Health. 2022;14(4):556-65.

12. Vilar E, Collado-Boira E, Guerrero C, Folch-Ayora A, Salas-Medina P, Hernando C, et al. Is

There a Role of Beetroot Consumption on the Recovery of Oxidative Status and Muscle Damage in Ultra-Endurance Runners? Nutrients. 2024;16(5):583.
13. Gallardo EJ, Coggan AR. What's in Your Beet Juice? Nitrate and Nitrite Content of Beet Juice Products Marketed to Athletes. Int J Sport Nutr Exerc Metab. 2019;29(4):345–9.
14. Wruss J, Waldenberger G, Huemer S, Uygun P, Lanzerstorfer P, Müller U, et al. Compositional characteristics of commercial beetroot products and beetroot juice prepared from seven beetroot varieties grown in Upper Austria. Journal of Food Composition and Analysis. 2015;42:46-55.
15. Larsen F, Weitzberg E, Lundberg J, Ekblom B. Effects of dietary nitrate on oxygen cost during exercise. Acta physiologica. 2007;191(1):59-66.
16. Bailey SJ, Winyard P, Vanhatalo A, Blackwell JR, Dimenna FJ, Wilkerson DP, et al. Dietary nitrate supplementation reduces the O2 cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans. Journal of applied physiology (Bethesda, Md : 1985). 2009;107(4):1144-55.
17. Domínguez R, Cuenca E, Maté-Muñoz JL, García-Fernández P, Serra-Paya N, Estevan MCL, et al. Effects of beetroot juice supplementation on cardiorespiratory endurance in athletes. A systematic review. Nutrients. 2017;9(1):43.

18. Jones AM. Dietary nitrate supplementation and exercise performance. Sports medicine (Auckland, NZ). 2014;44 Suppl 1(Suppl 1):S35-45.
19. McMahon NF, Leveritt MD, Pavey TG. The effect of dietary nitrate supplementation on endurance exercise performance in healthy adults: a systematic review and meta-analysis. Sports Medicine. 2017;47:735-56.
20. Williams TD, Martin MP, Mintz JA, Rogers RR, Ballmann CG. Effect of Acute Beetroot Juice Supplementation on Bench Press Power, Velocity, and Repetition Volume. Journal of strength and conditioning research. 2020;34(4):924-8.
21. Domínguez R, Maté-Muñoz JL, Cuenca E, García-Fernández P, Mata-Ordoñez F, Lozano-Estevan MC, et al. Effects of beetroot juice supplementation on intermittent high-intensity exercise efforts. Journal of the international society of sports nutrition. 2018;15:1-12.
22. Higaki Y, Hirshman MF, Fujii N, Goodyear LJ. Nitric oxide increases glucose uptake through a mechanism that is distinct from the insulin and contraction pathways in rat skeletal muscle. Diabetes. 2001;50(2):241-7.
23. Etgen Jr GJ, Fryburg DA, Gibbs EM. Nitric oxide stimulates skeletal muscle glucose transport through a calcium/contraction–and phosphatidylinositol-3-kinase–independent pathway. Diabetes. 1997;46(11):1915-9.

24. Sinaga FA, Sinaga RN, Manalu N. The Effect of Acute Beetroot Juice Supplementation After Strenuous Physical Activity on Creatine Kinase Levels. Journal of Physics: Conference Series. 2021;1819(1):012004.
25. Ashor AW, Shannon OM, Werner A-D, Scialo F, Gilliard CN, Cassel KS, et al. Effects of inorganic nitrate and vitamin C co-supplementation on blood pressure and vascular function in younger and older healthy adults: a randomised double-blind crossover trial. Clinical Nutrition. 2020;39(3):708-17.
26. Juraschek SP, Guallar E, Appel LJ, Miller III ER. Effects of vitamin C supplementation on blood pressure: a meta-analysis of randomized controlled trials. The American journal of clinical nutrition. 2012;95(5):1079-88.
27. May JM, Harrison FE. Role of vitamin C in the function of the vascular endothelium. Antioxidants & redox signaling. 2013;19(17):2068-83.
28. Mason SA, Keske MA, Wadley GD. Effects of Vitamin C Supplementation on Glycemic Control and Cardiovascular Risk Factors in People With Type 2 Diabetes: A GRADE-Assessed Systematic Review and Meta-analysis of Randomized Controlled Trials. Diabetes Care. 2021;44(2):618-30.
29. Berends JE, van den Berg LMM, Guggeis MA, Henckens NFT, Hossein IJ, de Joode M, et al. 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. 2019;20(9).
30. Basaqr R, Skleres M, Jayswal R, Thomas DT. The effect of dietary nitrate and vitamin C on endothelial function, oxidative stress and blood lipids in untreated hypercholesterolemic subjects: A randomized double-blind crossover study. Clinical Nutrition. 2021;40(4):1851-60.
31. Chamari K, Padulo J. ‘Aerobic’and ‘Anaerobic’terms used in exercise physiology: a critical terminology reflection. Sports medicine-open. 2015;1:1-4.
32. Hawley J, Williams M. Relationship between upper body anaerobic power and freestyle swimming performance. International journal of sports medicine. 1991;12(01):1-5.
33. Horswill C, Scott J, Galea P. Comparison of maximum aerobic power, maximum anaerobic power, and skinfold thickness of elite and nonelite junior wrestlers. International journal of sports medicine. 1989;10(03):165-8.
34. Jacobs PL, Mahoney ET, Johnson B. Reliability of arm Wingate Anaerobic Testing in persons with complete paraplegia. The journal of spinal cord medicine. 2003;26(2):141-4.
35. Metter EJ, Talbot LA, Schrager M, Conwit RA. Arm-cranking muscle power and arm isometric muscle strength are independent predictors of all-

cause mortality in men. Journal of applied physiology. 2004;96(2):814-21.
36. Horswill C, Miller J, Scott J, Smith C, Welk G, Van Handel P. Anaerobic and aerobic power in arms and legs of elite senior wrestlers. International journal of sports medicine. 1992;13(08):558-61.
37. Bogdanis GC, Nevill ME, Boobis LH, Lakomy H. Contribution of phosphocreatine and aerobic metabolism to energy supply during repeated sprint exercise. Journal of applied physiology. 1996;80(3):876-84.
38. Bogdanis G, Nevill M, Lakomy H. Effects of previous dynamic arm exercise on power output during repeated maximal sprint cycling. Journal of sports sciences. 1994;12(4):363-70.
39. Kohler RM, Rundell KW, Evans TM, Levine AM. Peak power during repeated wingate trials: implications for testing. The Journal of Strength & Conditioning Research. 2010;24(2):370-4.
40. Betteridge S, Bescós R, Martorell M, Pons A, Garnham AP, Stathis CC, et al. No effect of acute beetroot juice ingestion on oxygen consumption, glucose kinetics, or skeletal muscle metabolism during submaximal exercise in males. Journal of applied physiology (Bethesda, Md : 1985). 2016;120(4):391-8.
41. Lorenzo Calvo J, Alorda-Capo F, Pareja-Galeano H, Jiménez SL. Influence of Nitrate Supplementation on Endurance Cyclic Sports

Performance: A Systematic Review. Nutrients. 2020;12(6):1796.
42. Silva KVC, Costa BD, Gomes AC, Saunders B, Mota JF. Factors that moderate the effect of nitrate ingestion on exercise performance in adults: a systematic review with meta-analyses and meta-regressions. Advances in Nutrition. 2022;13(5):1866-81.
43. Levine M, Conry-Cantilena C, Wang Y, Welch RW, Washko PW, Dhariwal KR, et al. Vitamin C pharmacokinetics in healthy volunteers: evidence for a recommended dietary allowance. Proc Natl Acad Sci U S A. 1996;93(8):3704-9.
44. Manach C, Scalbert A, Morand C, Rémésy C, Jiménez L. Polyphenols: food sources and bioavailability. Am J Clin Nutr. 2004;79(5):727-47.
45. Menon A, Stojceska V, Tassou SA. A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies. Trends in Food Science & Technology. 2020;100:67-76.
46. Guelfi KJ, Jones TW, Fournier PA. The decline in blood glucose levels is less with intermittent high-intensity compared with moderate exercise in individuals with type 1 diabetes. Diabetes care. 2005;28(6):1289-94.
47. Janiszewska-Turak E, Tracz K, Bielińska P, Rybak K, Pobiega K, Gniewosz M, et al. The Impact of the Fermentation Method on the Pigment Content in Pickled Beetroot and Red Bell Pepper

Juices and Freeze-Dried Powders. Applied Sciences. 2022;12(12):5766.
48. FAO J. Fao food standard programme codex alimentarius commission 13th session. Report of the Thirty-Eight Session of the Codex Com on Food Hyg, Houston, United States of America, AliNorm. 2007.
49. Katan MB. Nitrate in foods: harmful or healthy? 2. The American journal of clinical nutrition. 2009;90(1):11-2.
50. Craig C, Marshall A, Sjostrom M, Bauman A, Lee P, Macfarlane D, et al. International physical activity questionnaire-short form. J Am Coll Health. 2017;65(7):492-501.
51. Pawlak-Chaouch M, Boissiere J, Gamelin FX, Cuvelier G, Berthoin S, Aucouturier J. Effect of dietary nitrate supplementation on metabolic rate during rest and exercise in human: a systematic review and a meta-analysis. Nitric Oxide. 2016;53:65-76.
52. Dotan R, Bar-Or O. Load optimization for the Wingate Anaerobic Test. Eur J Appl Physiol Occup Physiol. 1983;51(3):409-17.
53. Inbar O. The Wingate anaerobic test. Human Kinetics. 1996.
54. Jungersten L, Edlund A, Petersson AS, Wennmalm Å. Plasma nitrate as an index of nitric oxide formation in man: analyses of kinetics and confounding factors. Clinical Physiology. 1996;16(4):369-79.

55. Domínguez R, Garnacho-Castaño MV, Cuenca E, García-Fernández P, Muñoz-González A, de Jesús F, et al. Effects of Beetroot Juice Supplementation on a 30-s High-Intensity Inertial Cycle Ergometer Test. Nutrients. 2017;9(12).
56. Cuenca E, Jodra P, Pérez-López A, González-Rodríguez LG, Silva S, Herreros P, et al. 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. 2018;10.
57. Hashemi fard Es, Ebrahimi M. The effect of acute consumption of red beet juice on aerobic and anaerobic power of amateur karate girls. Journal of Sport and Exercise Physiology. 2022;15(3):102-11.
58. Hernández A, Schiffer TA, Ivarsson N, Cheng AJ, Bruton JD, Lundberg JO, et al. Dietary nitrate increases tetanic [Ca2+] i and contractile force in mouse fast-twitch muscle. The Journal of physiology. 2012;590(15):3575-83.
59. Ferguson SK, Hirai DM, Copp SW, Holdsworth CT, Allen JD, Jones AM, et al. Impact of dietary nitrate supplementation via beetroot juice on exercising muscle vascular control in rats. The Journal of physiology. 2013;591(2):547-57.
60. Haider G, Folland JP. Nitrate supplementation enhances the contractile properties of human skeletal muscle. Medicine and science in sports and exercise. 2014;46(12):2234-43.

61. Lundberg JO, Weitzberg E. NO generation from inorganic nitrate and nitrite: Role in physiology, nutrition and therapeutics. Archives of pharmacal research. 2009;32:1119-26.
62. Ignarro L, Adams J, Horwitz P, Wood K. Activation of soluble guanylate cyclase by NO-hemoproteins involves NO-heme exchange. Comparison of heme-containing and heme-deficient enzyme forms. Journal of Biological Chemistry. 1986;261(11):4997-5002.
63. Grgic J, Mikulic P. Caffeine ingestion acutely enhances muscular strength and power but not muscular endurance in resistance-trained men. European journal of sport science. 2017;17(8):1029-36.
64. Jones AM, Ferguson SK, Bailey SJ, Vanhatalo A, Poole DC. Fiber type-specific effects of dietary nitrate. Exercise and sport sciences reviews. 2016;44(2):53-60.
65. Bailey SJ, Varnham RL, DiMenna FJ, Breese BC, Wylie LJ, Jones AM. Inorganic nitrate supplementation improves muscle oxygenation, O2 uptake kinetics, and exercise tolerance at high but not low pedal rates. Journal of applied physiology. 2015;118(11):1396-405.
66. Coggan AR, Leibowitz JL, Kadkhodayan A, Thomas DP, Ramamurthy S, Spearie CA, et al. Effect of acute dietary nitrate intake on maximal knee extensor speed and power in healthy men and women. Nitric Oxide. 2015;48:16-21.

67. Rimer EG, Peterson LR, Coggan AR, Martin JC. Increase in maximal cycling power with acute dietary nitrate supplementation. International Journal of Sports Physiology and Performance. 2016;11(6):715-20.
68. Clifford T, Bell O, West DJ, Howatson G, Stevenson EJ. The effects of beetroot juice supplementation on indices of muscle damage following eccentric exercise. European journal of applied physiology. 2016;116:353-62.
69. Clifford T, Howatson G, West DJ, Stevenson EJ. Beetroot juice is more beneficial than sodium nitrate for attenuating muscle pain after strenuous eccentric-bias exercise. Applied Physiology, Nutrition, and Metabolism. 2017;42(11):1185-91.
70. Clifford T, Berntzen B, Davison GW, West DJ, Howatson G, Stevenson EJ. Effects of beetroot juice on recovery of muscle function and performance between bouts of repeated sprint exercise. Nutrients. 2016;8(8):506.
71. Clifford T, Allerton DM, Brown MA, Harper L, Horsburgh S, Keane KM, et al. Minimal muscle damage after a marathon and no influence of beetroot juice on inflammation and recovery. Applied Physiology, Nutrition, and Metabolism. 2017;42(3):263-70.
72. Daab W, Bouzid MA, Lajri M, Bouchiba M, Saafi MA, Rebai H. Chronic Beetroot Juice Supplementation Accelerates Recovery Kinetics following Simulated Match Play in Soccer Players.

Journal of the American College of Nutrition. 2021;40(1):61-9.
73. Bell PG, Walshe IH, Davison GW, Stevenson EJ, Howatson G. Recovery facilitation with Montmorency cherries following high-intensity, metabolically challenging exercise. Applied Physiology, Nutrition, and Metabolism. 2015;40(4):414-23.
74. Trombold JR, Barnes JN, Critchley L, Coyle EF. Ellagitannin consumption improves strength recovery 2-3 d after eccentric exercise. Med Sci Sports Exerc. 2010;42(3):493-8.
75. Owens DJ, Twist C, Cobley JN, Howatson G, Close GL. Exercise-induced muscle damage: What is it, what causes it and what are the nutritional solutions? European journal of sport science. 2019;19(1):71-85.
76. Marliss EB, Simantirakis E, Miles P, Purdon C, Gougeon R, Field CJ, et al. Glucoregulatory and hormonal responses to repeated bouts of intense exercise in normal male subjects. Journal of Applied Physiology. 1991;71(3):924-33.
77. Marliss EB, Vranic M. Intense exercise has unique effects on both insulin release and its roles in glucoregulation: implications for diabetes. Diabetes. 2002;51(suppl_1):S271-S83.
78. Kreisman SH, Mew NA, Arsenault M, Nessim SJ, Halter JB, Vranic M, et al. Epinephrine infusion during moderate intensity exercise increases glucose production and uptake. American Journal

of Physiology-Endocrinology and Metabolism. 2000;278(5):E949-E57.
79. Kreisman SH, Ah Mew N, Halter JB, Vranic M, Marliss EB. Norepinephrine infusion during moderate-intensity exercise increases glucose production and uptake. The Journal of Clinical Endocrinology & Metabolism. 2001;86(5):2118-24.
80. Sigal RJ, Purdon C, Bilinski D, Vranic M, Halter JB, Marliss EB. Glucoregulation during and after intense exercise: effects of beta-blockade. The Journal of Clinical Endocrinology & Metabolism. 1994;78(2):359-66.
81. Sigal RJ, Fisher SJ, Manzon A, Morais JA, Halter JB, Vranic M, et al. Glucoregulation during and after intense exercise: effects of α-adrenergic blockade. Metabolism. 2000;49(3):386-94.
82. Sigal RJ, Fisher S, Halter JB, Vranic M, Marliss EB. The roles of catecholamines in glucoregulation in intense exercise as defined by the islet cell clamp technique. Diabetes. 1996;45(2):148-56.
83. Riddell MC, Perkins BA. Type 1 diabetes and vigorous exercise: applications of exercise physiology to patient management. Canadian journal of diabetes. 2006;30(1):63-71.
84. Francescato MP, Geat M, Fusi S, Stupar G, Noacco C, Cattin L. Carbohydrate requirement and insulin concentration during moderate exercise in type 1 diabetic patients. Metabolism. 2004;53(9):1126-30.

85. Riddell M, Perkins BA. Exercise and glucose metabolism in persons with diabetes mellitus: perspectives on the role for continuous glucose monitoring. Journal of diabetes science and technology. 2009;3(4):914-23.
86. Wylie LJ, Mohr M, Krustrup P, Jackman SR, Ermιdis G, Kelly J, et al. Dietary nitrate supplementation improves team sport-specific intense intermittent exercise performance. Eur J Appl Physiol. 2013;113(7):1673-84.
87. Kwak JH, Paik JK, Kim HI, Kim OY, Shin DY, Kim H-J, et al. Dietary treatment with rice containing resistant starch improves markers of endothelial function with reduction of postprandial blood glucose and oxidative stress in patients with prediabetes or newly diagnosed type 2 diabetes. Atherosclerosis. 2012;224(2):457-64.
88. Tyler AP, Linder BA, Ricart K, Behrens CE, Ovalle F, Patel RP, et al. The Effects of Acute Beetroot Juice Intake on Glycemic and Blood Pressure Responses When Controlling for Medication in Individuals with Type 2 Diabetes: A Pilot Study. Nutrients. 2024;16(16):2636.
89. Jiang H, Torregrossa AC, Potts A, Pierini D, Aranke M, Garg HK, et al. Dietary nitrite improves insulin signaling through GLUT4 translocation. Free radical biology and medicine. 2014;67:51-7.
90. Mirmiran P, Houshialsadat Z, Gaeini Z, Bahadoran Z, Azizi F. Functional properties of beetroot (Beta vulgaris) in management of cardio-

metabolic diseases. Nutrition & metabolism. 2020;17:1-15.
91. Vasconcellos J, Henrique Silvestre D, dos Santos Baião D, Werneck-de-Castro JP, Silveira Alvares T, Paschoalin VMF. A Single Dose of Beetroot Gel Rich in Nitrate Does Not Improve Performance but Lowers Blood Glucose in Physically Active Individuals. Journal of Nutrition and Metabolism. 2017;2017(1):7853034.
92. Naziroglu M. M, Simsek and M. Kutlu, 2004. Moderate exercise with a dietary vitamin C and E combination protects against streptozotocininduced oxidative damage to the blood and improves fetal outcomes in pregnant rats. Clinical chemistry and laboratory medicine.42:511-7.
93. Bilbis L, Muhammad S, Saidu Y, Adamu Y. Effect of vitamins A, C, and E supplementation in the treatment of metabolic syndrome in albino rats. Biochemistry Research International. 2012;2012(1):678582.
94. Lbban E, Ashor A, Shannon OM, Idris I, Siervo M. Is vitamin C a booster of the effects of dietary nitrate on endothelial function? Physiologic rationale and implications for research. Nutrition. 2023;109:111995.
95. Riddell MC, Gallen IW, Smart CE, Taplin CE, Adolfsson P, Lumb AN, et al. Exercise management in type 1 diabetes: a consensus statement. Lancet Diabetes Endocrinol. 2017;5(5):377-90.

96. Cheuvront SN, Kenefick RW. Dehydration: physiology, assessment, and performance effects. Compr Physiol. 2014;4(1):257-85.
97. Robergs RA, Ghiasvand F, Parker D. Biochemistry of exercise-induced metabolic acidosis. Am J Physiol Regul Integr Comp Physiol. 2004;287(3):R502-16.
98. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability—part I: factors contributing to fatigue. Sports medicine. 2011;41:673-94.
99. Cuenca E, Jodra P, Pérez-López A, González-Rodríguez LG, Fernandes da Silva S, Veiga-Herreros P, et al. 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. 2018;10(9):1222.
100. Senefeld JW, Wiggins CC, Regimbal RJ, Dominelli PB, Baker SE, Joyner MJ. Ergogenic Effect of Nitrate Supplementation: A Systematic Review and Meta-analysis. Med Sci Sports Exerc. 2020;52(10):2250-61.
101. Tian C, Jiang Q, Han M, Guo L, Huang R, Zhao L, et al. Effects of Beetroot Juice on Physical Performance in Professional Athletes and Healthy Individuals: An Umbrella Review. Nutrients. 2025;17(12):1958.
102. TATLICI A. The effects of acute beetroot juice supplementation on lower and upper body isokinetic strength of the wrestlers. Journal of Men's Health. 2021;17(4):249-54.

103. Khosravi S, Ahmadizad S, Yekaninejad M, Karami M, Djafarian K. The effect of beetroot juice supplementation on muscle performance during isokinetic knee extensions in male Taekwondo athletes. Science & Sports. 2021;36(6):483. e1-. e7.
104. Delleli S, Ouergui I, Messaoudi H, Trabelsi K, Glenn J, Ammar A, et al. Does Beetroot Supplementation Improve Performance in Combat Sports Athletes? A Systematic Review of Randomized Controlled Trials. Nutrients. 2023;15:398.
105. Coutiño Díaz M, Prieto Martínez A, Zare R, Ali Redha A, Forbes SC. Evidence-Based Supplementation Strategies for Wrestlers: A Systematic Review. Current Nutrition Reports. 2025;14(1):86.
106. Bar-Or O. The Wingate anaerobic test an update on methodology, reliability and validity. Sports medicine. 1987;4:381-94.
107. Driss T, Vandewalle H. The measurement of maximal (anaerobic) power output on a cycle ergometer: a critical review. BioMed research international. 2013;2013(1):589361.
108. Barfield J-P, Sells PD, Rowe DA, Hannigan-Downs K. Practice effect of the Wingate anaerobic test. The Journal of Strength & Conditioning Research. 2002;16(3):472-3.