Journal of Science and Medicine in Sport 24 (2021) 80–84

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Beetroot juice supplementation increases concentric and eccentric muscle power output. Original investigation

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ARTICLE INFO

Article history:
Received 27 January 2020
Received in revised form 3 April 2020
Accepted 18 May 2020
Available online 27 May 2020

Keywords:
Nitrate
Nitric oxide
Resistance training
Squat
Muscle strength
Muscle Contraction

ABSTRACT

Objectives: Beetroot juice (BJ) supplementation has been reported to enhance skeletal muscle contractile function; however, it is currently unclear whether BJ supplementation elicits comparable improvements in power output during different types of skeletal muscle contractions. The purpose of the current study was to assess the effect of BJ supplementation on power output during concentric (CON) and eccentric (ECC) muscle contractions during a half-squat.

Design: In a randomized, double-blind placebo-controlled crossover design, eighteen adult males (age: 22.8 ± 4.9 y) completed two experimental testing sessions 2.5 h following the acute ingestion of 140 mL nitrate-rich BJ concentrate or a placebo.

Methods: Each experimental session comprised four sets of eight all-out half-squat repetitions with each set completed with a different moment intertia (0.025, 0.050, 0.075 and 0.100 kg·m^{-2}).

Results: Compared to placebo, BJ supplementation increased mean power output (MP) during the CON (ES: 0.61–1.01) and ECC (ES: 0.54–0.89; all $p < 0.05$) movement phases to a similar extent. Moreover, comparable increases in peak power output (PP) during the CON (ES: 0.86–1.24) and ECC (ES: 0.6–1.08; all $p < 0.05$) movement phases were observed following BJ supplementation.

Conclusion: Acute BJ supplementation increased mean and peak lower limb power output in the concentric and eccentric movement phases of a half-squat. These findings improve understanding of the effects of BJ supplementation on skeletal muscle contractile function and might have implications for enhancing sports performance in events where muscle power output is a key performance determinant.

Practical Applications

- The improvement in concentric and eccentric muscle power output over a range of moment inertias following acute beetroot juice ingestion supports the notion that beetroot juice supplementation can enhance skeletal muscle contractile function.
- These observations suggest that beetroot juice supplementation has the potential to enhance performance in short-duration high-intensity exercise settings such as single sprint and repeated sprint, and resistance exercise tasks.
- The results of this study suggest that BJ supplementation has the potential to improve resistance training quality which could translate into improved strength and power following a resistance training intervention

1. Introduction

Dietary supplementation with inorganic nitrate (NO_3^-) increases plasma and muscle nitrite (NO_2^-) concentrations[1] which can be further reduced to nitric oxide (NO), particularly under conditions of hypoxia and acidosis.[2] Initial studies indicated that dietary NO_3^- supplementation could improve submaximal exercise economy and capacity,[3–5] while more recent studies have reported that NO_3^- supplementation can enhance high-intensity exercise performance and skeletal muscle contractile function.[6–8]

Improvements in skeletal muscle contractile function following dietary NO_3^- supplementation has included increases in evoked contractile force[8–10] and voluntary concentric (CON) power output of the knee extensor muscles,[6,11,12] with no change in maximal isometric force production,[8–10] during single leg exercise. Although most of these studies have demonstrated positive effects of BJ supplementation following chronic BJ supplementation, improved power output has also been observed following

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https://doi.org/10.1016/j.jsams.2020.05.018
1440-2440/

acute BJ ingestion.[6,7,11] During two-legged exercise, chronic dietary NO_3^- supplementation has been reported to improve single or repeated all-out sprint performance in some,[7,13,14] but not all[13,15,16] studies. There is also evidence that acute BJ ingestion can improve all-out sprint performance.[17] Although NO_3^- supplementation appears to preferentially enhance contractile function in mouse fast-twitch skeletal muscle via improved skeletal muscle calcium (Ca^{2+}) handling,[18] NO_3^- supplementation studies in humans have reported improved force production in the absence of alterations to skeletal muscle Ca^{2+} handling proteins[10] and the magnitude of improvement in evoked force in human mixed fibre whole muscle[8–10] has been lower than mouse fast-twitch muscle.[18] It has been suggested that recruitment of fast-twitch skeletal muscle might be greater during eccentric muscle contractions (ECC).[19,20] If NO_3^- supplementation can preferentially improve contractile function in fast-twitch skeletal muscle, a greater improvement in power output might be expected during ECC compared to CON contractions. However, the effect of NO_3^- supplementation on CON and ECC contractile function has yet to be assessed. If BJ supplementation is more effective at enhancing power output during ECC contractions this might have implications for enhancing performance in sports involving more ECC contractions (e.g., running versus cycling).

The purpose of the current study was to test the hypothesis that acute NO_3^- supplementation would enhance power output during CON and ECC contractions during a half-squat movement completed at various moment inertias, and that this effect would be greater for ECC compared to CON at a given moment inertia.

2. Methods

Eighteen active adult males (age: 22.8 ± 4.9 years, height: 1.77 ± 0.10 m, weight: 74.4 ± 9.6 kg, body mass: 23.7 ± 2.4 $kg{\cdot}m^{-2}$) were recruited to participate in this study. All participants were physically active and reported completing moderate- to vigorous-intensity exercise (amateur team sport players or subjects that performed high-intensity training) at least 3 ± 1 times per week over the last year and self-reported no use of medicines or nutritional ergogenic aids during the study period and the preceding three months. Prior to testing, participants were informed of the experimental protocol and dietary guidelines and completed health questionnaires. Subsequently, participants provided written informed consent. This investigation was performed in accordance with the Declaration of Helsinki and the protocol was fully approved by the Ethics Committee of the Isabel I University prior to participant recruitment.

After an initial 2-wk familiarization period, participants completed the 2 experimental visits the following week, with the experimental visits separated by 72 h. Participants were randomly assigned in a double blind, placebo-controlled, crossover design to receive an acute 140 mL dose of 2 × 70 mL concentrated nitrate-rich beetroot shots providing 400 mg nitrate/70 mL (Beet It Sport® 400, James White Drinks, Ipswich, UK) or a nitrate-depleted placebo (see section below). Subsequently, lower limb mean (MP) and peak (PP) power outputs during half-squat exercise at different inertial loads (0.025, 0.050, 0.075 and 0.100 $kg{\cdot}m^{-2}$) were assessed using a flywheel device (K-Box 4, Exxentric®, Stockholm, Sweden). The experimental trials were completed at a similar time of day (±0.5 h) and environmental conditions (21–23 °C).

After arriving at the laboratory on the experimental testing days, participants ingested 140 mL of BJ (2 × 70 mL providing ~800 mg NO_3^-) or placebo (2 × 70 mL providing <0.1 mmol NO_3^-) 2.5 h prior to the onset of testing to coincide with the peak plasma $[NO_2^-]$.[21] The supplements were supplied in two unlabelled, 100 mL, brown glass bottles, with the placebo prepared as described previously.[22] Participants were asked to refrain from brushing their teeth or using mouthwash, chewing gum or sweets that could contain antimicrobial substances, such as chlorhexidine or xylitol, in the 24 h prior to the experimental sessions. Moreover, participants were instructed to avoid caffeine 24 h prior to testing and alcohol for the duration of the study. Participants followed a similar diet, consisting of 10% proteins, 30% lipids and 60% carbohydrates, and avoided NO_3^--rich foods (beetroot, ruccula, celery, turnip, spinach, lettuce, leak, cabbage, parsley, endives) for 24 h prior to the experimental visits.

Lower limb power output was assessed during a half-squat using a flywheel device which allowed participants to maximally complete concentric (CON) and eccentric (ECC) contractions. This flywheel device is a valid and reliable tool to assess power output values in inexperienced athletes.[23] Prior to commencing the testing protocol, a standardized warm-up was performed as described previously.[24] Participants completed 4 sets of 8 maximal repetitions with each set completed using different inertial loads (0.025, 0.050, 0.075 and 0.100 $kg{\cdot}m^{-2}$) and separated by 3 min passive recovery. Both the first and second repetitions of each set were used to accelerate the disks and excluded from data analysis, as described previously.[25] Participants were randomly allocated into ascending order and descending order with regard to the inertial load, and this order remained consistent within participants in the BJ and placebo conditions. Participants were required to perform the half-squat movement from a knee join angle of 90° to the full extension of the knees (180°), with no ankle extension allowed. Participants were instructed to push maximally through the entire range of motion of the CON action (90–180°) and then to gently resist during the initial 20°–30° of the subsequent ECC action before resisting maximally to produce eccentric overload and aiming to bring the disks to a stop at ~90° knee joint angle before initiating the next cycle.[25] Loud verbal encouragement was given to the participants during all testing sessions. During each repetition mean (average power output during the development of each phase) and peak (maximum power output during the development of each phase) power were recorded at a frequency of 100 Hz during the CON and ECC contractions via an optical receiver (SmartCoach, Europe AB, Stockholm, Sweden) coupled to the flywheel device. Data were subsequently processed using specialized software (SmartCoach Power Encoder, Europe AB, Stockholm, Sweden). Total power output (sum of CON and ECC power outputs) was also assessed.

All data are presented as mean ± standard deviation unless otherwise stated. After assessing for normal distribution via Kolmogorov–Smirnov tests, parametric statistical analyses were completed. A two-way, 2 [supplement (BJ and placebo)] × 8 [contraction type (CON 0.025 $kg{\cdot}m^{-2}$, CON 0.050 $kg{\cdot}m^{-2}$, CON 0.075 $kg{\cdot}m^{-2}$ CON and 0.100 $kg{\cdot}m^{-2}$ and ECC 0.025 $kg{\cdot}m^{-2}$, ECC 0.050 $kg{\cdot}m^{-2}$, ECC 0.075 $kg{\cdot}m^{-2}$ and ECC 0.100 $kg{\cdot}m^{-2}$)] repeated measures ANOVA was used to assess for statistically significant differences in MP, PP and total power output. The interclass correlation coefficient (ICC) of the ANOVA was calculated to provide insight into the reproducibility of the testing. Where the ANOVA revealed a significant difference, post hoc least significant difference *t*-tests were used to assess for statistically significant differences in MP, PP and total power output between BJ and placebo at each moment inertia for the CON and ECC contractions. In addition, the changes in MP, PP and total power between BJ and placebo at each moment inertia were compared for CON versus ECC contractions using paired simples *t*-tests. Effect size (ES) was calculated as Cohen's *d* with an ES of above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 defined as large, moderate, small and trivial, respectively. Statistical significance was set at $p < 0.05$. All statistical tests were performed using the software package SPSS version 20.0 (SPSS, Chicago, IL).

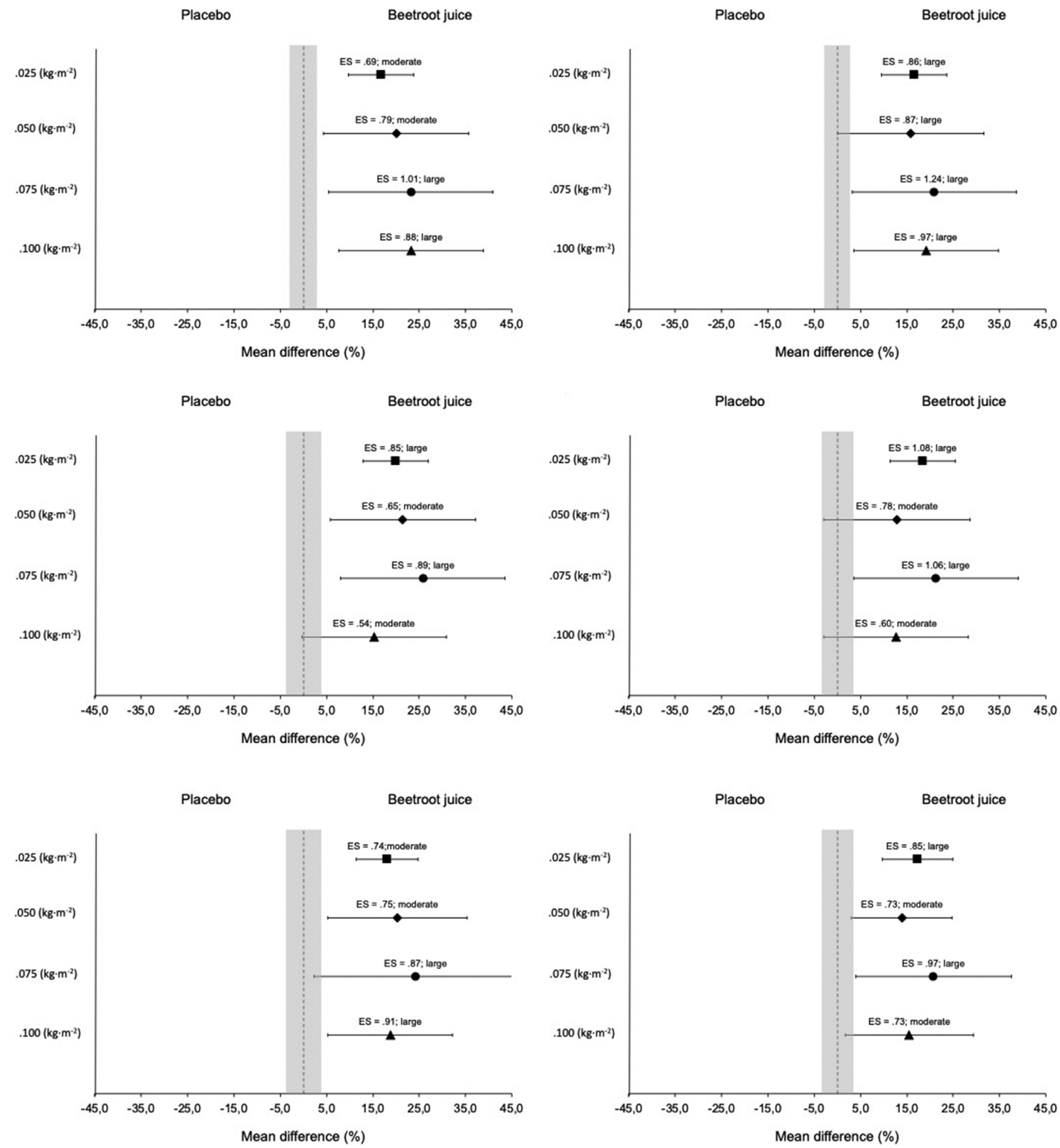

Fig. 1. Differences in concentric mean (upper left panel) and peak (upper right panel) power, eccentric mean (centre left panel) and peak (centre right panel) power and total mean (bottom left panel) and total peak (bottom right panel) power at different moment inertias between the beetroot juice and placebo conditions. Data are presented as mean ± SD. Trivial area highlighted in grey was calculated from the smallest worthwhile change.

3. Results

There were significant main effects for supplement ($p < 0.01$) and contraction type ($p = 0.02$) without differences in supplement × contraction type ($p = 0.738$) for MP, and the ICC average measures was 0.983. Compared to placebo, BJ ingestion increased MP during CON and ECC contractions, as well as total MP, at moment inertias of 0.025, 0.050, 0.075 and 0.100 kg·m^{-2} ($p < 0.01$, ES = 0.54–1.1, Table 1). There were no differences between the improvements in MP with BJ at any of the moment inertias in the ECC compared to the CON contractions ($p > 0.05$, Fig. 1). For total MP, there was a main effect for supplement ($p < 0.001$) and contraction type ($p = 0.001$), but not for supplement × contraction type ($p = 0.416$). The ICC average measures was 0.971. Compared to placebo, BJ ingestion increased total MP at all moment inertias analyzed ($p < 0.01$, ES = 0.74–0.91, Table 1).

There were significant main effects for supplement ($p < 0.01$) and contraction type ($p = 0.01$) without differences in supplement × contraction type ($p = 0.339$) for PP, and the ICC average measures was 0.978. Compared to placebo, BJ ingestion increased PP during CON and ECC contractions, as well as total PP, at moment inertias of 0.025, 0.050, 0.075 and 0.100 kg·m^{-2} ($p < 0.01$, ES = 0.60–1.24, Table 2). There were no differences between the improvements in PP with BJ at any of the moment inertias in the ECC compared to the CON contractions ($p > 0.05$, Fig. 1). For total PP, it was observed a main effect for supplement ($p < 0.001$) and contraction type ($p = 0.003$), but not for supplement × contraction type ($p = 0.151$). The ICC average measures was 0.963. Compared to placebo, BJ ingestion increased total power output at all moment inertias analyzed ($p < 0.01$, ES = 0.73–0.97, Table 1).

Table 1
Effects of beetroot juice (BJ) supplementation on concentric mean power (MP_{CON}), eccentric mean power (MP_{ECC}) and total mean power (MP_{TOTAL}) outcomes at different moment inertias (MI) when comparing to placebo (PLA) condition.

MI ($kg \cdot m^{-2}$)		PLA	BJ	P
0.025	MP_{CON}	644 ± 153	750 ± 173	<0.001
	MP_{ECC}	572 ± 131	684 ± 154	<0.001
	MP_{TOTAL}	1216 ± 278	1434 ± 324	<0.001
0.050	MP_{CON}	598 ± 140	709 ± 146	<0.001
	MP_{ECC}	583 ± 162	687 ± 150	<0.001
	MP_{TOTAL}	1181 ± 295	1396 ± 293	<0.001
0.075	MP_{CON}	551 ± 120	672 ± 157	<0.001
	MP_{ECC}	580 ± 145	709 ± 177	<0.01
	MP_{TOTAL}	1130 ± 259	1382 ± 328	<0.001
0.100	MP_{CON}	493 ± 120	600 ± 127	<0.001
	MP_{ECC}	540 ± 139	615 ± 150	<0.01
	MP_{TOTAL}	1033 ± 255	1214 ± 273	<0.001

Table 2
Effects of beetroot juice (BJ) supplementation on concentric peak power (PP_{CON}), eccentric peak power (PP_{ECC}) and total peak power (PP_{TOTAL}) outcomes at different moment inertias (MI) when comparing to placebo (PLA) condition.

MI ($kg \cdot m^{-2}$)		PLA	BJ	P
0.025	PP_{CON}	1075 ± 205	1251 ± 249	<0.001
	PP_{ECC}	1005 ± 176	1195 ± 265	<0.001
	PP_{TOTAL}	2080 ± 376	2447 ± 505	<0.001
0.050	PP_{CON}	1025 ± 181	1182 ± 226	<0.001
	PP_{ECC}	1034 ± 172	1168 ± 261	<0.01
	PP_{TOTAL}	2059 ± 334	2351 ± 479	<0.001
0.075	PP_{CON}	937 ± 158	1132 ± 239	<0.001
	PP_{ECC}	1003 ± 187	1201 ± 261	<0.01
	PP_{TOTAL}	1940 ± 329	2333 ± 492	<0.001
0.100	PP_{CON}	851 ± 161	1008 ± 197	<0.001
	PP_{ECC}	955 ± 191	1070 ± 230	<0.01
	PP_{TOTAL}	1807 ± 347	2078 ± 413	<0.001

4. Discussion

Consistent with our first experimental hypothesis, acute BJ ingestion increased CON and ECC power output during a half-squat movement compared to placebo. However, in contrast with our second experimental hypothesis, BJ ingestion improved power output during CON and ECC contractions by a similar magnitude. These novel observations improve understanding of the effects of BJ supplementation on skeletal muscle contractile function and, therefore, possibly some of the mechanisms by which this dietary intervention might be ergogenic.

In the present study, BJ ingestion improved power output during CON and ECC contractions by a similar magnitude (15–25%) across a range of different moment inertias. The improvement in CON power output following BJ supplementation is consistent with previous observations[12]; however, the magnitude of improvement in our study is greater than has been reported previously. For example, BJ supplementation has been reported to increase peak power output during maximal CON knee extensor contractions at a moderate-to-high angular velocity (>4.17 rad/s) in healthy men and women by ~11%.[11] In part, these inter-study discrepancies might be linked to different devices and exercise modalities used to assess power output. Other factors mentioned in the limitations section of this discussion could also have contributed to the disparate magnitude of effect on power output following BJ supplementation in this study compared to previous studies. The magnitude of improvement in CON power output in our study with BJ ingestion is similar to that observed after caffeine supplementation (MP_{CON} = +24.5–26.5% and PP_{CON} = +22.1–24.2%)[24] and 7 weeks of flywheel training (MP_{CON} = +30.8 and PP_{CON} = +36.6%).[25] However, the principal novel observation of the current study is an improvement in ECC power output following BJ compared to placebo supplementation (MP_{ECC} = 15.2–25.8% and PP_{ECC} = 12.7–21.2% in BJ versus placebo). The magnitude of improvement in MP_{ECC} and PP_{ECC} with BJ supplementation in the current study is similar to that obtained after caffeine supplementation (6 $mg \cdot kg^{-1}$) (MP_{ECC} = 22.7–24.8% and PP_{ECC} = 18.8–25.0%),[24] but lower than the improvements observed in MP_{ECC} after 7 (MP_{ECC} = +25.5% and PP_{ECC} = +41.0%)[25] weeks of strength training with flywheel devices. Therefore, our findings support the notion that BJ supplementation can enhance skeletal muscle power output[12] and extend previous observations by suggesting that BJ supplementation confers a comparable improvement in power output during CON and ECC contractions.

Participants acutely ingested 140 mL of NO_3^--rich BJ, which provided 400 mg NO_3^-, or a NO_3^--depleted placebo prior to completing the CON and ECC contractions in the current study. This dose of BJ has been consistently reported to elevate circulating plasma [NO_2^-],[26] which can undergo an O_2-indpenedent, one-electron reduction to NO.[2] The improvements in skeletal muscle contractile function reported in the current study and previous studies[8–10] following NO_3^- supplementation is purported to be mediated via NO-related physiological processes.[12] Short-term (7 days) NO_3^- supplementation has been reported to increase isometric contractile force in type II (fast-twitch) mouse skeletal muscle in association with increased content of Ca^{2+} handling proteins.[18] However, while 7 days NO_3^- supplementation has been reported to increase contractile force in human skeletal muscle, these effects were independent of changes in the content of Ca^{2+} handling proteins.[10] Consistent with these observations, the improvement in CON and ECC power output reported in the current study is unlikely to have been mediated by changes in the content of skeletal muscle Ca^{2+} handling or myofibrillar proteins owing to the acute BJ supplementation protocol employed. However, an increase in CON power output following acute BJ ingestion corroborates some previous observations.[6,11] These effects may be mediated by cyclic guanosine monophosphate-dependent and -independent posttranslational modifications of Ca^{2+} handling and myofibrillar proteins.[12]

Notwithstanding the increase in MP, PP and total power output following BJ compared to placebo ingestion at each moment inertia for the CON and ECC contractions in the present study, there are a number of limitations of this study which should be acknowledged. Firstly, while the flywheel device utilized to assess power output during CON and ECC contractions in the present study has been reported to demonstrate good test-retest reliability, a wide coefficient of repeatability has been reported for this device[23] which could have influenced the magnitude of the ergogenic effect of BJ in this study. In addition, it should be acknowledged that the placebo administered in this study would have tasted different to the BJ supplement which could have elicited a placebo effect in some of the participants and accounted for the large magnitude of effect of BJ supplementation in the present study. Although the dose of nitrate-rich BJ and the timing relative to the start of the power output assessments in this study would have been expected to coincide with the peak increase in plasma [nitrite], we concede that a limitation of this study was that we did not assess plasma [nitrite] in our participants. This precluded us from assessing for correlations between the magnitude of improvement in power output and plasma [nitrite]. We also did not verify the nitrate content of the BJ and placebo supplements. Finally, the movement velocity was not assessed in the current study which precludes assessment of how the magnitude of the effect following BJ ingestion was impacted by movement velocity, as reported elsewhere.[11]

5. Conclusions

In conclusion, acute supplementation with BJ increased both CON and ECC power output across a range of moment inertias during half-squat exercise. These novel observations are consistent with the notion that BJ supplementation can improve skeletal muscle contractile function and might be ergogenic in sports where muscle power output is a key performance determinant.

Conflict of interest

The authors declare no conflict of interest associated with this article.

Acknowledgments

The authors would like to thank the participants of this study. The costs of the beetroot supplement were paid by the University Isabel I, Burgos, Spain.

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