

Beetroot juice and exercise performance

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Abstract: Increased sales and consumption of organic and natural foods reflect consumers heightened interest in promoting health and improving athletic performance. Of these products, beetroot and its constituents have become increasingly popular in the arena of exercise performance, mainly due to the high concentrations of nitrate. Studies have indicated beetroot juice (BRJ) may improve exercise time to exhaustion, running performance, and increase muscular efficiency during moderate intensity exercise. The purpose of this review is to examine the efficacy of BRJ to serve as an ergogenic aid in athletic performance. It appears that BRJ may provide modest performance enhancement; however, more research is needed to clearly identify mechanisms of action and proper dosing patterns to maximize the performance benefits of BRJ.

Keywords: beetroot, nitrate, betaine, sports nutrition

Introduction

In the world of athletic competition, margins of victory are becoming smaller, and in some cases may literally come down to a fraction of a second or the ability to contract a single motor unit one more time. Thus, athletes are constantly in pursuit of any advantage to improve athletic performance. Some athletes may turn toward nutritional supplements, from both natural and organic sources, to provide this edge. Not surprisingly, during the period from 1999 to 2009, the US market for organic and natural foods experienced an increase in annual growth rate from 22.5% to 31.1%, whereas the supplement market had a decline in annual growth rate from 34.5% to 24.8%.¹ In addition, the forecast for “Estimated Compound Annual Sales Growth” from 2010 to 2017 is projected to be 5% for supplements compared to 8% for natural and organic foods.¹ Given this trend for organic and natural food products, it is particularly relevant to understand whether there is an added performance benefit due to the ingredients within these food products acting additively, synergistically, or even negatively compared to a concentrated dose of the isolated bioactive ingredient from the whole food or product.

Currently, one of the more popular natural foods considered to help athletic performance is beetroot (*Beta vulgaris*), one of the most common varieties of beet in North America. Beetroot is an excellent source of antioxidants and micro-nutrients, including (in descending order by weight) potassium, betaine, sodium, magnesium, vitamin C, and nitrate (NO₃⁻) and contains 29 kcal per 100 g.² The color of beetroot stems from its purple and yellow pigments (betacyanin and betaxanthin, respectively), known collectively as betalains. These betalains have

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potential antioxidant capabilities.^{3,4} Interestingly, BRJ has been marketed on the Internet to support digestive and blood health, improve energy, be a natural cleanser, and increase levels of nitric oxide (NO) leading to increased blood flow. In addition, BRJ has been indicated to possess anticancer properties, can lower the risk of coronary events (stroke and peripheral vascular disease), lower blood pressure, and reduce inflammation.⁵ These claims have boosted the popularity of BRJ.

Several of the properties of BRJ mentioned above have been hypothesized to enhance athletic performance. For example, betaine has been shown to favorably enhance performance outcomes.⁶ However, the additive or synergistic effects of the constituents contained within BRJ have not been extensively studied. Nevertheless, both anecdotal and scholarly evidence supports the use of BRJ to produce faster finish times,^{7,8} increase time to exhaustion,⁹⁻¹¹ reduce steady-state oxygen (O₂) consumption,^{9,10} increase peak power,^{7,12} and increase work rate at the gas exchange threshold¹² (see Table 1). Therefore, this review will examine the impact specifically of BRJ, rather than each constituent, on athletic performance.

Beetroot, NO₃⁻, and NO

Beetroot has a high NO₃⁻ content (>250 mg/100 g of fresh weight), among the highest assessed, and other foods high in NO₃⁻ include spinach, celery, lettuce, and carrot juice.¹³ NO₃⁻ can be reduced to nitrite via bacteria in the oral cavity and by specific enzymes (eg, xanthine oxidase) within tissues. There are several pathways to metabolize nitrite to NO and other biologically active nitrogen oxides.¹⁴ NO is a signaling molecule formed in the endothelium by the enzyme endothelium NO synthase, which triggers the vasculature to relax (vasodilatation) by interacting with vascular smooth muscle leading to increased blood flow.^{15,16} NO facilitates increased blood flow at rest¹⁷ and during exercise.¹⁸

Given these properties, NO has gained a lot of attention for possible exercise improvements including increased O₂, glucose, and other nutrient uptake to better fuel working muscles. Bradley et al¹⁹ and Balon and Nadler²⁰ reported NO production contributed significantly to exercise-induced skeletal muscle glucose uptake, independent of skeletal muscle blood flow. Currently there is no means to provide NO supplementation through the diet, as it is a gas, thus BRJ and its high NO₃⁻ concentration is used as a means to generate NO endogenously. In fact, up until this point, much of the support for NO use to improve exercise performance

has relied heavily on “borrowed science” using amino acids such as L-arginine.²¹ Much more impressive is the growing body of scientific data in support of whole food sources of inorganic NO₃⁻, such as that found in BRJ, and improved athletic performance.

BRJ, dietary NO₃⁻, and exercise performance

Aerobic exercise

Lansley et al⁹ examined whether the exercise performance benefits of BRJ were attributed to its high NO₃⁻ content or its other potentially bioactive compounds. Nine healthy, physically active men consumed either 0.5 L of BRJ (6.2 mmol/day of NO₃⁻) or 0.5 L of NO₃⁻-depleted BRJ placebo (0.0034 mmol/day of NO₃⁻) for 6 days followed by acute bouts of submaximal and high-intensity (to exhaustion) running and incremental knee extension exercises. BRJ consumption increased plasma nitrite by 105% and reduced the O₂ cost for constant-work-rate moderate and severe-intensity running by ~7% compared to placebo. In addition, time to exhaustion was increased during severe-intensity running by ~15% and incremental knee extension exercise by ~5% with BRJ compared to placebo.⁹ These findings suggest that the performance benefit (O₂ sparing and enhanced exercise tolerance) of consuming BRJ is attributed to its high NO₃⁻ content. More recently, Murphy et al⁸, using a double-blind placebo-controlled crossover trial, had eleven recreationally fit men and women consume either baked beetroot (200 g with ≥500 mg NO₃⁻) or an isocaloric placebo (cranberry relish) 75 minutes prior to performing a 5 km time trial (TT) treadmill run to determine whether whole beetroot consumption would improve running performance. They observed a nonsignificant, 41-second faster finishing time (12.3 ± 2.7 versus 11.9 ± 2.6 km/hour, respectively; *P*=0.06) following beetroot consumption compared to placebo. Interestingly, during the last 1.1 miles (1.8 km) of the 5 km run, running velocity was 5% faster (12.7 ± 3.0 versus 12.1 ± 2.8 km/hour, respectively; *P*=0.02) and rating of perceived exertion was lower (13.0 ± 2.1 versus 13.7 ± 1.9, respectively; *P*=0.04) during the beetroot trial compared to the placebo. The authors suggest that nitrite levels may have continued to rise during the 5 km run, resulting in the late race benefits. Therefore, it appears that the ingestion of whole-foods containing inorganic NO₃⁻ (such as beetroot or BRJ) increases plasma nitrite and ultimately NO levels, which favorably affect the cellular and vascular pathways, which likely result in the observed improvements in athletic performance.⁸ For a summary, see Table 1.

Table 1 Summary of research using beetroot juice for performance changes in humans

Author group	Number of participants	Study design	BRJ dose	Performance improvements reported
Bailey et al ¹⁰	8	Double-blind, placebo-controlled crossover	0.5 L of BRJ (5.5 mmol/day of NO ₃ ⁻) or placebo	<ul style="list-style-type: none"> Reduced the amplitude of the VO₂ slow component and increased the time to task failure by ~16% during fixed high intensity exercise 25% increased time to failure 25% reduction in the increase in pulmonary VO₂ from rest to low-intensity exercise 52% reduction in the amplitude of the VO₂ slow component during high-intensity exercise allowing for slower increase to the VO₂ max Significant reduction in end-exercise VO₂ at low-intensity and the mean VO₂ over the final 30 seconds of exercise (except at failure) 36% reduction in PCr degradation during low-intensity exercise (knee extensions) 59% reduction in the PCr during high-intensity exercise
Bailey et al ¹¹	7	Randomized, double-blind crossover	0.5 L BRJ (5.1 mmol/day NO ₃ ⁻) or placebo	<ul style="list-style-type: none"> VO₂ max, peak power output, and the work rate associated with the anaerobic threshold were higher than the placebo and baseline after 15 days of BRJ consumption Reduced the VO₂ for constant-work-rate moderate and severe-intensity running by ~7% Time to exhaustion was increased during severe-intensity running by ~15% and incremental knee extension exercise by ~5% Reduced time to completion and significantly increased power output during the 4 km TT (2.8% and 5%, respectively; P<0.05) Reduced time to completion and significantly increased power output during the 16 km TT (2.7% and 6%, respectively; P<0.05) Increased exercise tolerance (walked 18% longer before claudication pain onset and experienced a 17% longer peak walking time) Decreased fractional O₂ extraction (48% decrease in Hgb peak-curve amplitude)
Vanhatalo et al ⁴⁵	8	Balanced crossover	0.5 L BRJ (5.2 mmol/day NO ₃ ⁻) or placebo	<ul style="list-style-type: none"> BRJ reduced hypoxic muscle metabolic "perturbation" (indicated by PCr degradation and Pi accumulation) during high-intensity exercise, and returned exercise tolerance to normoxic conditions BRJ eliminated the reduction in the PCr recovery rate with hypoxia Nonsignificant improvement in running velocity Running velocity was 5% faster during the last 1.1 miles (1.8 km) of the 5 km run Mean VO₂ was lower at 45% and 65% of maximal power with BRJ than with placebo (P<0.05)
Lansley et al ⁹	9	Randomized, double-blind crossover	0.5 L of BRJ (6.2 mmol/day of NO ₃ ⁻) or placebo	<ul style="list-style-type: none"> Completion of the 10 km TT was 1.2% faster with BRJ than with placebo (P<0.005) and this was associated with a 2.1% higher mean power output (P<0.05)
Lansley et al ⁷	9	Randomized crossover	0.5 L BRJ (6.2 mmol of NO ₃ ⁻) or placebo	
Kenjale et al ²⁷	8	Randomized, open-label crossover	0.5 L of BRJ (18.1 mmol/L NO ₃ ⁻) or placebo	
Vanhatalo et al ³²	9	Randomized, double-blind crossover	0.75 L of BRJ (9.3 mmol NO ₃ ⁻) or placebo	
Murphy et al ⁸	11	Double-blind, placebo-controlled crossover	200 g beetroot with ≥500 mg NO ₃ ⁻ or placebo	
Cermak et al ⁴⁶	12 male trained cyclists	Double-blind, repeated-measures crossover	140 mL of concentrated BRJ (~8 mmol NO ₃ ⁻) or placebo	

(Continued)

Table 1 (Continued)

Author group	Number of participants	Study design	BRJ dose	Performance improvements reported
Cermak et al ⁴⁷	20 male trained cyclists	Double-blind, repeated-measures crossover	Single bolus of BRJ (140 mL; 8.7 mmol NO ₃ ⁻) or placebo, 1 hour prior to cycling TT	<ul style="list-style-type: none"> Plasma nitrite concentrations were significantly higher after BRJ ingestion No change in TT performance, power output, or heart rate between groups
Bond et al ⁴⁸	14 well-trained junior male rowers	Randomized, double-blind crossover	0.5 L of BRJ/day (5.5 mmol NO ₃ ⁻) or placebo for 6 days	<ul style="list-style-type: none"> Improved repeated high-intensity rowing ergometer performance times by 0.4% across all repetitions and in the later stages of exercise (repetitions 4–6) by 1.7%
Wilkerson et al ⁴⁹	8 well-trained cyclists	Randomized, double-blind crossover	0.5 L of BRJ/day	<ul style="list-style-type: none"> Improved completion of a 50 mile TT by 0.8% ($P > 0.05$). Power output was not different, but VO₂ was lower with BRJ versus placebo
Masschelein et al ³⁰	15 physically active males	Randomized, single-blind crossover	0.07 mmol/kg of body weight/day or placebo for 6 days	<ul style="list-style-type: none"> In hypoxia, during rest and moderate intensity exercise, arterial O₂ saturation was 3.5% and 2.7% higher and VO₂ was lower with BRJ versus placebo
Christensen et al ²⁶	10 elite male cyclists (8 completed TT testing)	Randomized, single-blind crossover	0.5 L of BRJ or placebo for 6 days	<ul style="list-style-type: none"> Reductions in VO₂ max attenuated by 5% in hypoxia with BRJ versus placebo No effects on VO₂ kinetics or performance
Kelly et al ²²	9 recreationally active males	Randomized, double-blind crossover	0.5 L of BRJ or placebo for 7–12 days	<ul style="list-style-type: none"> BRJ improved exercise tolerance by 17%, 16%, and 12% for 60%, 70%, and 80% peak power cycling, respectively
Muggeridge et al ⁵⁰	9 competitive amateur male cyclists	Randomized, double-blind crossover	70 mL of BRJ (~5 mmol NO ₃ ⁻) or 70 mL of placebo (~0.01 mmol NO ₃ ⁻) before 2nd and 3rd of three performance trials (performance trials consisted of 15 minutes submaximal steady-state exercise at 60% of maximum work rate and a 16.1 km TT)	<ul style="list-style-type: none"> Single dose of BRJ lowered VO₂ during a submaximal exercise of 60% maximal work rate BRJ significantly improved 16.1 km TT performance
Muggeridge et al ²⁴	8 trained male kayakers	Randomized, double-blind crossover	70 mL of BRJ or 70 mL of tomato juice (placebo) before 2nd and 3rd of three performance trials (performance trials consisted of 15 minutes paddling at 60% of maximum work rate, five 10-second all-out sprints and a 1 km TT)	<ul style="list-style-type: none"> BRJ caused a lower VO₂ during steady-state exercise compared to placebo BRJ showed no effect on repeated supramaximal sprint or on a 1 km TT kayaking performance
Wyllie et al ²⁵	10 healthy men	Balanced crossover	70 mL (4.2 mmol NO ₃ ⁻), 140 mL (8.4 mmol NO ₃ ⁻), or 0.28 L (16.8 mmol NO ₃ ⁻) of BRJ or no supplement	<ul style="list-style-type: none"> 140 mL and 280 mL of BRJ intake reduced steady-state VO₂ during moderate-intensity exercise by 1.7% and 3.0% and increased time-to-task failure by 14% and 12%, respectively 70 mL ingestion of BRJ did not alter physiological responses to moderate-intensity or severe-intensity exercise No additional benefits to ingestion of 16.8 mmol compared to that of 8.4 mmol of NO₃⁻

Abbreviations: BRJ, beetroot juice; Hgb, hemoglobin; NO₃⁻, nitrate; O₂, oxygen; Pi, inorganic phosphate; TT, time trial; VO₂, oxygen consumption; VO₂ max, maximal oxygen consumption.

Power output and performance

Given the impact of BRJ on aerobic performance, it would seem likely that BRJ would also favorably impact other markers of athletic performance. The effects of BRJ ingestion on power output, oxygen consumption (VO_2), and cycling time trial (TT) performance was examined by Lansley et al⁷ using nine competitive male cyclists who consumed either 0.5 L BRJ (6.2 mmol of NO_3^-) or placebo containing NO_3^- -depleted BRJ (0.0047 mmol of NO_3^-) before each TT of 4 km or 16 km. BRJ consumption increased plasma nitrite by 138% and resulted in significantly reduced time to completion and increased power output during both the 4 km (2.8% and 5%, respectively; $P < 0.05$) and 16 km TTs (2.7% and 6%, respectively; $P < 0.05$) compared to the placebo treatment.⁷

Similarly, in a crossover study, Bailey et al¹⁰ supplemented eight healthy, recreationally active men with 0.5 L of BRJ (5.5 mmol/day of NO_3^-) or a low-calorie blackcurrant juice cordial (negligible NO_3^- content) for 6 days, and they performed moderate (80% gas exchange threshold) and intense cycling (70% of the difference between the power output at the gas exchange threshold and VO_2 peak) protocols during the last 3 days. BRJ ingestion increased the average plasma nitrite by 96% and reduced muscle deoxyhemoglobin amplitude by 13%, suggesting that fractional O_2 extraction was reduced. In addition, BRJ consumption reduced the amplitude of the VO_2 slow component (defined as a delayed onset of VO_2 consumption during high intensity exercise. Similar to the previous data reported, these authors concluded that increased dietary inorganic NO_3^- consumption from BRJ has the potential to improve high-intensity exercise tolerance.¹⁰

While it appears that BRJ does improve exercise performance, the minimal time needed to use BRJ for a performance benefit remains to be elucidated. One attempt to answer these questions was reported by Vanhatalo et al.¹² These authors examined the effects of acute (1 and 5 days) and chronic (15 days) BRJ consumption on a moderate-intensity exercise bout (90% gas exchange threshold) and an incremental cycle ergometer ramp test (increasing work rate by 1 W every 2 seconds [30 W/minute]) to exhaustion. Eight healthy subjects (five males, three females) consumed either 0.5 L BRJ (5.2 mmol/day NO_3^-) or a placebo (blackcurrant juice cordial with negligible NO_3^- content) for 15 days and were exercise tested on days 1, 5, and 15. Plasma nitrite was significantly increased on all test days following BRJ compared to placebo. The O_2 cost of moderate-intensity exercise (increase in VO_2 relative to the

increase in external work rate) was lower during BRJ ingestion and was maintained throughout the 15 days ($P = 0.002$; effect size, 0.51). Maximal O_2 consumption ($\text{VO}_{2\text{max}}$), peak power output, and the work rate associated with the anaerobic threshold were all higher following 15 days of BRJ consumption compared to placebo and baseline conditions. In addition, systolic and diastolic blood pressures were reduced by 4 mmHg (−3% and −5%, respectively). Compared with placebo, systolic blood pressure was significantly lower at 2.5 hours as well as at 2, 12, and 15 days post-ingestion of BRJ (95% confidence interval −12.4 to −1.1; $P < 0.05$). The mean diastolic blood pressure was significantly different between groups ($P = 0.003$) and decreased with BRJ compared to placebo (95% confidence interval −4.3 to −1.3; $P < 0.01$). The authors concluded that acute (1–5 days) dietary NO_3^- supplementation significantly decreased blood pressure and the O_2 cost of submaximal exercise and increased VO_2 max and peak power output, and these outcomes were maintained for at least 15 days with continued BRJ supplementation.¹² While more studies agree with these findings,^{22–25} not all agree.²⁶ Interestingly, Christensen et al²⁶ recently noted that in highly trained cyclists with an average VO_2 max of 72 ± 4 mL/kg/min, consuming 0.5 L of BRJ had no effect on performance. This suggests that the impact of BRJ may be influenced by the training status of the individual consuming this product (see Table 1).

In nonathletic populations, the impact of BRJ may also have a positive influence. In fact, Kenjale et al²⁷ studied patients with peripheral arterial disease to test whether BRJ would increase plasma nitrite and exercise tolerance and decrease muscle fractional O_2 extraction. Eight participants consumed either 0.5 L of BRJ (18.1 mmol/L NO_3^-) or an isocaloric placebo on two separate occasions, while performing an incremental, graded treadmill running test. The increased plasma nitrite following BRJ consumption was associated with increased exercise tolerance (walked 18% longer before claudication pain onset and experienced a 17% longer peak walking time) and decreased fractional O_2 extraction. Thus, these findings support dietary NO_3^- ingestion, in the form of BRJ, increases nitrite-related NO signaling, resulting in enhanced peripheral tissue oxygenation in hypoxic areas and increased exercise tolerance in individuals with peripheral arterial disease.²⁷ While it appears that BRJ supplementation may be useful for both athletes and nonathletes alike in order to improve aerobic exercise performance, the impact of BRJ on resistance exercise performance is not as clear.

BRJ and resistance exercise

Extremely limited research has been conducted on the effects of BRJ and resistance exercise.¹¹ In addition, only three studies to date have been published that investigate the use of betaine (a major BRJ constituent) on resistance exercise performance.^{6,28,29} The findings from these betaine studies are equivocal, with the overarching theme being a modest improvement in resistance exercise performance.

With specific regard to BRJ on resistance exercise performance, Bailey et al¹¹ enlisted seven recreationally active males (age 28 ± 7 years) to consume either 0.5 L/day of BRJ (5.1 mmol/day NO_3^-) or a placebo (blackcurrant juice cordial with negligible NO_3^- content) for 6 days. During the last 3 days of supplementation, participants completed low and high (15% and 30% maximal voluntary isometric contractions, respectively) intensity “step” knee extension tests. Results indicated that BRJ more than doubled plasma nitrite concentrations and resulted in a 25% reduction in pulmonary VO_2 from rest to low-intensity exercise.¹¹ In addition, BRJ consumption resulted in a 36% reduction in the amount of phosphocreatine (PCr) degraded during low-intensity exercise (knee extensions) and a 59% reduction during high-intensity exercise compared to placebo.¹¹ These reductions in PCr usage were accompanied by a reduction in the total ATP utilization during both high and low-density exercise. However, the authors speculate that the reduced O_2 cost may be due to an improved coupling between ATP hydrolysis and skeletal muscle force production rather than an increased mitochondrial phosphate/ O_2 ratio (P/O ratio), which is the number of inorganic phosphate (Pi) molecules used for ATP synthesis for every O_2 consumed.¹¹ Another intriguing finding of this study was a 25% increased time to task failure (knee extension exercise) in all seven participants that consumed BRJ. This may be a result of sparing PCr stores and reducing the O_2 cost of exercise.¹¹

BRJ and hypoxic conditions

Compelling research is highlighting the effectiveness of performing exercise under moderate hypoxic conditions to improve performance.^{30,31} To determine whether the dietary NO_3^- in BRJ would improve metabolism and oxidative function in muscle during hypoxic conditions, Vanhatalo et al³² performed a double-blind crossover study with nine healthy participants, moderately trained in recreational sport. The participants consumed either 0.75 L of BRJ (9.3 mmol NO_3^-) or a NO_3^- -depleted placebo (0.006 mmol NO_3^-) before performing low (28 ± 2 W) and high intensity (48 ± 4 W)

knee extension exercises to exhaustion. These exercises were performed under normoxic (control) and hypoxic ($14.45\% \pm 0.05\% \text{O}_2$) conditions, where the percentage of O_2 was controlled by a filtration system. BRJ reduced hypoxic muscle metabolic “perturbation” (indicated by PCr degradation and Pi accumulation) during high-intensity exercise and returned exercise tolerance to normoxic conditions. In addition, BRJ eliminated the reduction in the PCr recovery rate with hypoxia.³² These findings suggest BRJ consumed under hypoxic conditions provides an additional performance stimulus to working muscle and allows participants to function as if in a normoxic environment. Practically, this research implicates that athletes may benefit from BRJ consumption when working at very high-intensities and/or at altitude by enhancing O_2 utilization. Overall, the majority of the published research indicates a benefit for athletes from BRJ supplementation.

Dosing of BRJ and dietary NO_3^-

It is important to note that the acute dose of NO_3^- used in research studies ranges from 5.1 mmol (0.32 g) to 18.1 mmol (1.12 g) which is four to 12 times greater than the typical daily dietary NO_3^- intake in the United States.³³

Mechanisms of action for BRJ

Several mechanisms have been postulated for the various exercise improvement effects of BRJ. A reduction in PCr degradation and the reduction of build-up of adenosine diphosphate (ADP) and Pi at the same relative exercise intensity following BRJ consumption^{7,12} are likely mechanisms responsible for the decrease in O_2 cost (oxidative phosphorylation) of exercise and increased time to exercise failure (reduced muscle fatigue). Indeed, NO may lessen fatigue at the same exercise intensity due to a slowing of cross-bridge cycling kinetics by reducing calcium (Ca^{2+}) sensitivity by decreasing the number of cross bridges in the force generating state³⁴ or by inhibiting the mechanical properties and adenosine triphosphatase activity of myofibrils.³⁵ NO also modulates ryanodine receptor (Ca^{2+} release channels) activity by S-nitrosylation or oxidation of several classes of cysteine residues associated with the protein, thereby affecting Ca^{2+} release³⁶ and inhibiting Ca^{2+} -adenosine triphosphatase activity.³⁷ Consequently, these data suggest that BRJ may have a regulatory influence on the ATP cost of force production.¹¹

Larsen et al¹⁴ reported that muscle mitochondria extracted after NO_3^- supplementation indicated an improvement in oxidative phosphorylation efficiency (P/O ratio) and a decrease

in state 4 respiration (basal respiration associated with maintenance costs). The improved mitochondrial P/O ratio correlated with a reduction in O_2 cost at rest and during exercise. These authors¹⁴ and others^{7,32} indicate that NO_3^- reduces the expression of ATP/ADP translocase, an enzyme involved in proton conductance.¹⁴ ATP/ADP translocase is a transporter protein that facilitates the mobilization of ATP and ADP into and out of the inner mitochondrial membrane for ATP use.³⁸

Several proposed mechanisms for BRJ to enhance PCr/muscle recovery during hypoxia, such as that experienced during high-intensity exercise scenarios, include increased efficiency of mitochondria and increased delivery and perfusion of O_2 to working muscles.³² Whether overall cellular metabolism is enhanced is yet to be determined. It is possible that gene expression regulation, mitochondrial biogenesis, immunomodulation, and cell cycle/apoptosis control also account for the ergogenic effects of BRJ.^{8,39–41}

Antioxidant benefits

While improvements in performance of both aerobic and anaerobic exercise are reported via numerous proposed mechanisms, the impact of BRJ serving as a potent dietary antioxidant must be explored. As such, the antioxidant capabilities of BRJ and its constituents could further enhance the ability to sustain exercise, or possibly, aid in recovery from exercise.

Intense exercise, especially to exhaustion, has been shown to increase free radical concentrations in the muscles and liver by two to three times.⁴² Interestingly, several recent investigations have examined the potential antiradical properties of certain constituents of BRJ, namely betacyanins and betaxanthins, the main pigments of red beetroots.³ In addition, Kanner et al⁴ reported that linoleate peroxidation by cytochrome c was inhibited by betanin from red beets. It was suggested that regular beetroot consumption may provide protection against certain oxidative stress-related disorders in humans,⁴ and therefore may serve as a useful strategy to enhance recovery from exercise and subsequent exercise performance.

Conclusion

Research examining the efficacy of BRJ as an exercise enhancer appears to support its use. Most studies have shown BRJ or its constituents to increase number of repetitions, power, and time to fatigue.^{7–12,27,43} However, while at least one of these performance improvements is typical, they are not all observed in each of these studies. NO_3^- from BRJ, working alone or synergistically with other components of

BRJ, has demonstrated a reduced O_2 cost of exercise.^{9–12,27} The primary mechanism of action for the efficacy of BRJ to improve performance appears to be related to muscle bioenergetics, specifically attenuating the decline in PCr concentrations, coupled with enhanced efficiency of oxidative phosphorylation. However, more research is required to fully elucidate all of the potential mechanisms. Of note for consumers, the effective dose yielding performance and health benefits in scientific research studies of dietary NO_3^- is approximately 1,500 mg/L.^{11,27} Nevertheless, BRJ appears to improve performance without any side effects, although more standardized research methods may be needed to clarify the above findings as well as potential contraindications of BRJ for endurance athletes (ie, potential hypotension concerns from over consumption of NO_3^-). Interestingly, other constituents of BRJ, such as betalain, betaine, betanin, betacyanin, and betaxanthin, may offer additional performance⁴⁴ and antioxidant health⁴ benefits, albeit via alternate mechanisms.

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The authors report no conflicts of interest in this work.

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