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Effects of Nitrate-Rich Beetroot Supplements on Anaero-bic Power, Speed-Characteristic Performance, and Explosive Leg Strength on Football Players

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Abstract

Athletic performance is influenced by physiological and nutritional factors, with dietary nitrate supplementation emerging as a potential er-gogenic aid. Beetroot, rich in nitrates, has been shown to enhance oxygen utilization and muscular efficiency. However, its effects on anaerobic power, speed-characteristic perfor-mance, and explosive leg strength in football players remain unclear. This study investi-gates the impact of beetroot supplementation on these key performance variables. Meth-ods: A controlled experimental study was conducted with 20 youth football players from Al-Sinaa Club (aged 17-19 years), randomly assigned into an experimental group (n = 10) consuming 500 ml of nitrate-rich beetroot juice daily for eight weeks and a control group (n = 10) maintaining their regular diet. Performance assessments included the Wingate Anaerobic Test for anaerobic power, a 30-meter sprint test for speed, and vertical jump and three-hop tests for explosive strength. Data were analyzed using SPSS software. Re-sults: The experimental group exhibited significant improvements compared to the con-trol group. Peak anaerobic power increased significantly (p = 0.000), and the time to reach peak anaerobic power decreased (p = 0.000). Maximum sprint speed improved, with sprint times decreasing (p = 0.000). Speed-specific strength in both legs and explosive leg strength also showed significant enhancements (p < 0.05). Conclusions: Nitrate-rich beet-root supplementation effectively enhances anaerobic power, sprint performance, and ex-plosive strength in football players. These findings support its use as a natural ergogenic aid for optimizing high-intensity sports performance. Future research should explore long-term effects and dosage optimization.

Keywords: *Beetroot Supplementation, Anaerobic Power, Sprint Performance, Explosive Strength, Football Training, Dietary Nitrates, Sports Nutrition.*

Introduction

Athletic performance is influenced by various physiological and nutritional factors, with dietary supplementation emerging as a key area of research. Among these, ni-trate-rich beetroot supplements have gained significant attention due to their potential to enhance oxygen utilization, muscular efficiency, and overall athletic performance. The vasodilatory properties of dietary nitrates, which enhance blood flow and reduce oxygen cost during exercise, have been widely studied in endurance sports. However, their impact on anaerobic power, speed-

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characteristic performance, and explosive leg strength, which are critical in high-intensity sports like football, remains a topic of ongoing debate.

The purpose of this study is to examine the effects of beetroot supplementation on anaerobic performance, sprinting ability, and lower-body explosive strength in football players. While some studies suggest that nitrate supplementation enhances muscle con-tractility and power output [1] , others argue that its benefits are more pronounced in endurance rather than anaerobic activities [2] . The conflicting evidence highlights the need for a more comprehensive investigation into how beetroot-derived nitrates influence high-intensity, short-duration efforts characteristic of football.

This study aims to bridge the gap in existing research by evaluating the acute and chronic effects of beetroot supplementation on key performance parameters. A recent sys-tematic review and meta-analysis suggested that nitrate supplementation may enhance muscle power and endurance performance [3], but limited data exist on football-specific explosive strength and sprint performance. Through a controlled experimental approach, the research assesses whether nitrate intake translates into measurable improvements in anaerobic power, sprint speed, and leg explosiveness.

The findings of this study could have practical implications for nutrition strategies in elite football, potentially guiding dietary recommendations to enhance performance in high-intensity scenarios. Additionally, emerging evidence indicates that beetroot supple-mentation may reduce neuromuscular fatigue during simulated match play [4], further supporting its relevance for high-intensity, intermittent sports like football.

By clarifying the role of beetroot supplementation in anaerobic sports, this research contributes to both sports science and applied nutrition, offering insights relevant to ath-letes, coaches, and sports nutritionists aiming to optimize training and competition out-comes.

Materials and Methods

Research Design

The researcher employed an experimental approach due to its suitability for the study's objectives. Specifically, a pre-test/post-test design with two equal groups (experi-mental and control) was used to measure the effects of nitrate-rich beetroot supplementa-tion on anaerobic power, speed-characteristic performance, and explosive leg strength in football players.

Participants

The study sample consisted of 20 youth football players from Al-Sinaa Club, aged 17-19 years. The participants were randomly assigned by lottery method into two groups:

- Experimental group (n = 10): Received nitrate-rich beetroot supplementation.
- Control group (n = 10): Maintained their regular diet without supplementation.

Selection Criteria

Inclusion Criteria:

- Registered football players actively training with Al-Sinaa Club.
- Aged between 17-19 years.

- No history of musculoskeletal injuries in the past six months.
- Free from chronic diseases that could interfere with nitrate metabolism.

Exclusion Criteria:

- Players undergoing any additional dietary supplementation.
- History of metabolic disorders affecting nitrate metabolism.
- Inability to complete the intervention due to injury or personal reasons.

2.4. Selection Criteria

Functional Variables:

- Highest anaerobic capacity (W): Peak anaerobic power recorded during the test.
- Lowest anaerobic capacity (W): Minimum anaerobic power output recorded at the end of the test.
- Time to reach highest anaerobic capacity (s): Duration required to attain peak anaerobic power.

Physical Variables:

- Explosive strength of the lower limbs (cm): Measured through a vertical jump test.
- Maximum speed (s): Assessed through a 30-meter sprint test.
- Power characterized by speed (m): Measured using the three-hop test for both the right and left legs.

Testing Procedures

Anaerobic Power Assessment

Wingate Anaerobic Test (WAnT):It is a test to measure anaerobic capacity, where the subject exerts maximum effort on a stationary bike for 30 seconds, with resistance deter-mined according to their weight at a rate of 75 grams per kilogram of body weight. Per-formance is measured based on the number of wheel rotations, where each full rotation on the Monark bike equals a distance of 6 meters. The test aims to measure peak anaerobic power, minimum anaerobic power, and the time required to reach peak anaerobic power.

The test begins with measuring the subject's weight, followed by a 3-minute warm-up using light resistance (1 - 2 kg). During the final minutes of the warm-up, the subject accelerates the bike to maximum speed for 3 - 5 seconds, repeating this two or three times. After the warm-up, the bike is adjusted by entering the subject's data to determine the required resistance. The seat height is set so that the knee flexion angle is 10 degrees when the feet are placed on the pedals, and the foot strap is secured to prevent slipping during the test. The test procedure is explained to the subject, emphasizing the starting signal. The revolutions per minute (RPM) counter is activated to monitor the speed. The load is gently lifted, and the subject begins pedaling at maximum speed (not less than 80 RPM) for 3 seconds before the actual measurement starts. Then, the load is lowered gently, and the measurement begins. The subject continues to pedal at maximum speed for 30 seconds without stopping, with encouragement to maintain the highest possible speed. After the test ends, results are printed directly from the bike, and the subject is advised to perform cool-down exercises to avoid any negative physiological effects.

Explosive Strength of Lower Limbs

Vertical Jump Test (Countermovement Jump): This test aims to measure the explosive power of the legs, where the player stands facing the wall, holding a piece of chalk in one fully extended hand, then marks the highest point they can reach from a standing posi-tion. After that, the player bends the knees, swings the arms forward and upward, extends the knees, and jumps as high as possible to mark the highest point reached by the hand during the jump. The heels must remain on the ground when making the first mark. The distance between the first mark (from standing) and the second mark (from jumping) is measured, and the player is given three attempts, with the best attempt recorded. The tools used in the test include a metal measuring tape, a suitably high wall, a piece of chalk, a data recorder, and a registration form.

Maximum Speed Test

30-Meter Sprint Test: This test aims to measure the player's maximum speed, where a running track of no less than 50 meters is designated, with a start line and a finish line separated by 30 meters, while the start line is preceded by a 10-meter acceleration zone. The player stands behind the start line, and upon hearing the whistle, begins running at maximum speed until crossing the start line, at which point the timing begins, continuing until the player crosses the finish line. The player is given only one attempt, and the time taken to cover 30 meters is recorded to the nearest fraction of a second. The tools used in the test include a stopwatch, a whistle, four markers, and a measuring tape.

Speed-Power Test

Three-Hop Test: This test measures the speed-specific strength of the leg muscles, where the player stands on the starting line on one foot, and upon hearing the signal, per-forms three consecutive hops for the maximum possible distance. The player must push off from a stationary position and perform the movements quickly. Each player is given two attempts for each leg (right and left), and the best attempt is recorded. The distance from the starting line to the point reached by the player is measured and rounded to the nearest centimeter. The tools used include a stopwatch, a registration form, a metric measuring tape, and a whistle.

Intervention Protocol

The intervention lasted 8 weeks, during which the experimental group received a standardized nitrate-rich beetroot supplementation, while the control group maintained their regular diet without any supplementation. The experimental group consumed 500 ml of 100% natural beetroot juice per day, which contained approximately 6.4 mmol (400 mg) of nitrate. The juice was consumed 2 hours before training sessions to allow sufficient nitrate conversion to nitric oxide (NO), optimizing its ergogenic effects.

Both the experimental and control groups followed the same football training pro-gram to ensure that the only variable affecting performance was the supplementation. Training sessions were conducted 5 days per week, lasting 90 minutes per session, and included a 15-minute warm-up (dynamic stretching, mobility drills, and low-intensity running), 30 minutes of technical drills (ball control, passing, shooting, and tactical posi-tioning), 30 minutes of strength and conditioning exercises (plyometric drills, sprint exer-cises, and agility training), and a 15-minute cool-down (static stretching and low-intensity jogging for recovery).

To ensure compliance, the experimental group was closely monitored, and partici-pants were instructed to avoid dietary modifications or any additional supplementation during the intervention period. A weekly questionnaire was conducted to verify adherence and check for any gastrointestinal discomfort or adverse effects. Pre- and post-test meas-urements were taken to assess changes in anaerobic power, speed-characteristic perfor-mance, and explosive leg strength, ensuring scientific validity, dietary control, and stand-ardized training conditions for accurate evaluation of the effects of nitrate-rich beetroot supplementation on football players' performance.

Statistical Analysis

Collected data were analyzed using SPSS software.

Results

Variables	Unit of Measurement	Pre-Test Mean	SD	Post-Test Mean	SD	Mean Difference	SD Difference	Calculated t-value	Error Level (p-value)	Significance
Peak Anaerobic Power	Watts	549.910	47.412	572.059	51.474	22.149	24.506	2.858	0.019	Significant
Minimum Anaerobic Power	Watts	326.593	56.781	338.531	63.646	11.938	13.864	2.728	0.023	Significant
Time to Peak Anaerobic Power	Seconds	5.716	0.617	5.325	0.350	0.392	0.380	3.258	0.010	Significant
Maximum Speed (30 meters)	Seconds	4.002	0.103	3.892	0.113	0.110	0.078	4.450	0.002	Significant
Speed-Specific Strength (Right Leg)	Meters	6.250	0.331	6.270	0.324	0.020	0.023	2.739	0.023	Significant
Speed-Specific Strengt	Meters	6.130	0.347	6.460	0.251	0.330	0.151	6.898	0.000	Significant

h (Left Leg)										
Explosive Strength (Both Legs)	cm	42.200	4.341	42.600	4.858	0.400	1.429	0.885	0.339	Random

Table 1. Differences in Means, Standard Deviations, Calculated t-value, and Significance of Differences Between Pre- and Post-Test Results for the Control Group

*A result is considered significant if the error level is ≤ 0.05.

The results of Table (1) showed that the training program alone had a positive effect on some physical variables in the control group of football players, who did not consume beetroot supplements rich in nitrates. However, it was not sufficient to achieve significant improvement in all aspects. Peak anaerobic power increased from 549.910 watts to 572.059 watts with a significant difference (p=0.019), indicating a limited improvement in the players' ability to produce energy during maximal efforts. Additionally, minimum anaerobic power increased from 326.593 watts to 338.531 watts (p=0.023), reflecting a slight improvement in anaerobic endurance. As for the time to reach peak anaerobic pow-er, it decreased from 5.716 seconds to 5.325 seconds (p=0.010), indicating an improvement in the muscular system's response, but this improvement remains limited compared to the group that received supportive supplements.

Regarding maximum speed over 30 meters, the control group recorded a slight im-provement, with the time decreasing from 4.002 seconds to 3.892 seconds (p=0.002), re-flecting an improvement in acceleration ability, but not to the extent that nutritional sup-plements could achieve. Speed-specific strength also showed a slight improvement, in-creasing for the right leg from 6.250 meters to 6.270 meters (p=0.023), and for the left leg from 6.130 meters to 6.460 meters (p=0.000), indicating a gradual effect of the training program, though not sufficiently effective to achieve a major advancement. As for explo-sive strength in both legs, it increased from 42.200 cm to 42.600 cm, but this improvement was not significant (p=0.339), indicating that training alone was not enough to make a clear difference in this variable.

Based on these results, it is evident that the training program contributed to a signifi-cant improvement in some physical variables, but it was not sufficient to achieve substan-tial improvements in all aspects, particularly in explosive strength. This suggests that combining training with dietary supplements, such as nitrate-rich beetroot, may be more effective in improving physical performance and enhancing players' abilities to a greater extent.

Variables	**Unit of Measurement**	**Pre-Test Mean**	**SD**		**Post-Test Mean**	**SD**	**Mean Difference**	**SD Difference**	**Calculated t-value**	**Error Level (p-value)**	**Significance**
Peak Anaero	Watts	544.708	51.521		763.663	106.102	218.955	106.495	15.645	0.000	Significant

bic Power										
Minimum Anaerobic Power	Watts	299.787	47.673	402.018	56.331	102.231	71.701	6.502	0.001	Significant
Time to Peak Anaerobic Power	Seconds	5.606	0.474	4.128	0.618	1.477	0.724	4.509	0.000	Significant
Maximum Speed (30 meters)	Seconds	3.995	0.125	3.781	0.102	0.214	0.043	15.645	0.000	Significant
Speed-Specific Strength (Right Leg)	Meters	6.210	0.337	6.942	0.248	0.732	0.105	21.986	0.000	Significant
Speed-Specific Strength (Left Leg)	Meters	6.220	0.155	6.680	0.175	0.460	0.151	9.662	0.000	Significant
Explosive Strength (Both Legs)	cm	40.000	3.972	48.100	5.486	8.100	3.315	7.727	0.000	Significant

Table 2. Differences in Means, Standard Deviations, Calculated t-value, and Significance of Differences Between Pre- and Post-Test Results for the Experimental Group

*A result is considered significant if the error level is ≤ 0.05.

The results of Table (2) showed that nitrate-rich beetroot supplements, alongside the training program, had a clear positive effect on anaerobic power, speed-specific perfor-mance, and explosive strength in football players in the experimental group. Peak anaero-bic power increased significantly from 544.708 watts to 763.663 watts, with a significant difference (p=0.000), reflecting a noticeable improvement in the players' ability to generate energy during maximal efforts. Similarly, minimum anaerobic power increased from 299.787 watts to 402.018 watts (p=0.001), indicating an improvement in anaerobic en-durance, which is crucial in sports that require repeated short bursts of high-intensity ef-fort.

Additionally, the time to reach peak anaerobic power decreased from 5.606 seconds to 4.128 seconds (p=0.000), indicating a faster muscular response in reaching maximum anaerobic capacity, which contributes to improved performance in situations requiring rapid acceleration. As for maximum speed over 30 meters, it improved significantly, with the time decreasing from 3.995 seconds to 3.781 seconds (p=0.000), reflecting a substantial development in the players' acceleration and quick reaction ability.

Regarding speed-specific strength, both the right and left legs showed a clear im-provement. The right leg increased from 6.210 meters to 6.942 meters (p=0.000), while the left leg improved from 6.220 meters to 6.680 meters (p=0.000), indicating improved muscle coordination and the ability to execute fast movements more efficiently. Meanwhile, ex-plosive strength in both legs increased from 40.000 cm to 48.100 cm (p=0.000), highlight-ing the positive impact of the supplements in enhancing the ability to generate quick force, which is essential for jumping and rapid takeoff during play.

Based on these results, it is evident that the combination of beetroot supplements and the training program led to significant improvements in all studied physical variables. The supplements contributed to increasing anaerobic efficiency, improving acceleration, and enhancing explosive strength, making them an effective option for improving athletic performance in football players compared to training alone.

Variables	**Unit of Measurement**	**Control Group Mean**	**SD**	**Experimental Group Mean**	**SD**	**Calculated t-value**	**Error Level (p-value)**	**Significance**
Peak Anaerobic Power	Watts	572.059	51.474	763.663	106.102	5.138	0.000	Significant
Minimum Anaerobic Power	Watts	338.531	63.646	402.018	56.331	2.362	0.030	Significant
Time to Peak Anaerobic Power	Seconds	5.325	0.350	4.128	0.618	5.324	0.000	Significant
Maximum Speed (30 meters)	Seconds	3.892	0.113	3.781	0.102	2.309	0.033	Significant
Speed-Specific Strength (Right Leg)	Meters	6.270	0.324	6.942	0.248	5.210	0.000	Significant
Speed-Specific Strength (Left Leg)	Meters	6.460	0.251	6.680	0.175	2.270	0.036	Significant

Explosive Strength (Both Legs)	cm	42.600	4.858	48.100	5.486	2.373	0.029	Significant

Table 3. Means, Standard Deviations, Calculated t-value, and Significance of Differences Between the Two Research Groups in the Post-Test

***A result is considered significant if the error level is ≤ 0.05.**

The results of Table (3) showed that the experimental group, which consumed ni-trate-rich beetroot supplements alongside the training program, significantly outper-formed the control group, which relied only on training, in all studied variables. The peak anaerobic power recorded in the experimental group was 763.663 watts, compared to 572.059 watts in the control group, with a significant difference (p=0.000), indicating a major improvement in energy production during maximal efforts. Additionally, mini-mum anaerobic power increased to 402.018 watts in the experimental group compared to 338.531 watts in the control group (p=0.030), demonstrating that beetroot supplements helped players maintain a higher level of anaerobic energy during performance.

Regarding the time to reach peak anaerobic power, the experimental group showed a significant decrease, recording 4.128 seconds compared to 5.325 seconds in the control group (p=0.000), reflecting an improvement in the muscle system's response speed in reaching maximum anaerobic capacity. The experimental group also excelled in maxi-mum speed over 30 meters, recording 3.781 seconds compared to 3.892 seconds in the control group (p=0.033), indicating a clear enhancement in acceleration ability.

Concerning speed-specific strength, the experimental group demonstrated a signifi-cant improvement compared to the control group. The right leg increased to 6.942 meters compared to 6.270 meters in the control group (p=0.000), while the left leg improved to 6.680 meters compared to 6.460 meters in the control group (p=0.036), reflecting a notable development in motor muscular capacity due to the effect of the supplements.

As for explosive strength of both legs, the experimental group outperformed the con-trol group, recording 48.100 cm compared to 42.600 cm (p=0.029), indicating an im-provement in the players' ability to generate rapid force, which is essential for activities requiring jumping or quick takeoff.

Based on these results, it is evident that the combination of beetroot supplements and the training program led to significant improvements in all physical variables compared to training alone. The supplements contributed to increasing anaerobic capacity, enhanc-ing acceleration, and improving speed-specific strength and explosive power, confirming their effectiveness in supporting athletic performance and enhancing players' physical abilities.

Discussion

The results of this study provide compelling evidence regarding the effects of struc-tured training and nitrate-rich beetroot supplementation on anaerobic power, speed, and explosive leg strength in football players. The findings demonstrate that while structured training alone led to moderate improvements, the addition of beetroot supplementation significantly enhanced performance across all measured variables.

Structured training alone contributed to noticeable improvements in anaerobic pow-er, as reflected in peak and minimum anaerobic power values. These findings are con-sistent with previous studies indicating that systematic training enhances anaerobic per-formance to a certain degree [5-6] . However, the improvements observed in the control group were relatively modest compared to those in the experimental group. Research suggests that these adaptations could be further amplified with dietary nitrate supple-mentation, which increases nitric oxide (NO) bioavailability, facilitating better oxygen uti-lization and muscular efficiency.

Similarly, the reduction in sprint time over 30 meters among control group partici-pants aligns with research demonstrating that training improves neuromuscular coordi-nation and muscular power output. However, studies have indicated that nitrate supple-mentation can further enhance sprint performance by optimizing ATP turnover and re-ducing the oxygen cost of exercise [7] . The relatively minor gains observed in speed-specific strength and the statistically insignificant changes in explosive leg strength in the control group reinforce the idea that training alone may not be sufficient to optimize all aspects of anaerobic performance.

In contrast, the experimental group, which combined structured training with ni-trate-rich beetroot supplementation, demonstrated significant enhancements in anaerobic power, speed, and explosive leg strength. These results strongly support the hypothesis that dietary nitrates serve as an effective ergogenic aid. The substantial increases in peak and minimum anaerobic power observed in the experimental group align with research suggesting that nitrate supplementation enhances anaerobic metabolism, likely through improved mitochondrial efficiency and increased NO availability. These physiological adaptations facilitate greater vasodilation, improved blood flow, and enhanced oxygen utilization in muscle tissue [8-9] .

The improvements in time to reach peak anaerobic power and 30-meter sprint per-formance among the experimental group further support the role of dietary nitrates in en-hancing neuromuscular efficiency and fast-twitch muscle fiber activation. Research has demonstrated that dietary nitrates enhance phosphocreatine resynthesis, a critical factor in high-intensity efforts, thereby improving sprint performance and reducing fatigue onset [10] . This enhanced energy turnover likely explains the superior gains observed in the experimental group compared to the control group.

Moreover, the experimental group exhibited significant improvements in speed-specific strength and explosive leg strength, highlighting the impact of nitrate sup-plementation on neuromuscular efficiency and muscle contractility. Studies by Jonvik and Coggan & Peterson [11-12] have shown that dietary nitrates improve calcium han-dling and muscle contraction speed, which could explain the superior explosive strength observed in the experimental group. These findings suggest that nitrate supplementation enhances force production and neuromuscular coordination, critical components of foot-ball performance.

A direct comparison between the control and experimental groups reinforces the ef-fectiveness of nitrate-rich beetroot supplementation in optimizing athletic performance. The experimental group consistently outperformed the control group across all perfor-mance metrics, confirming that the combination of structured training and dietary nitrates leads to superior physiological adaptations. The observed improvements in anaerobic power and sprint performance align with studies demonstrating that nitrate supplemen-tation enhances mitochondrial function, ATP production, and NO-mediated vasodilation [13-14] . The greater reductions in sprint times in the experimental group highlight the role of nitrate supplementation in enhancing neuromuscular function and oxygen delivery, resulting in more efficient sprinting and acceleration.

The findings have significant implications for sports nutrition and training strate-gies. Given the importance of anaerobic power, sprinting ability, and explosive strength in football, incorporating nitrate-rich beetroot supplementation into training regimens could provide a competitive advantage. This study supports the use of beetroot as a natural and effective ergogenic aid, aligning with the increasing interest in dietary interventions for performance enhancement. The ability of nitrate supplementation to improve muscle effi-ciency and enhance explosive movements makes it a promising strategy for athletes en-gaged in high-intensity, intermittent sports [15].

While this study provides strong evidence for the performance-enhancing effects of nitrate supplementation, several areas warrant further investigation. Future research should explore the long-term effects of nitrate supplementation on muscle adaptation and injury prevention over a full competitive season. Additionally, examining individual var-iability in response to dietary nitrates—considering genetic predisposition, training expe-rience, and dietary habits—could provide valuable insights into personalized supple-mentation strategies. Further studies should also determine the optimal dosage and tim-ing of nitrate intake to maximize its ergogenic benefits in different athletic populations. Comparative research assessing the effectiveness of nitrate supplementation relative to other ergogenic aids, such as caffeine and creatine, could further refine its application in sports nutrition [17].

The findings of this study confirm that while structured training alone induces mod-erate improvements in anaerobic power, speed, and explosive strength, these gains are significantly enhanced when combined with nitrate-rich beetroot supplementation. The results support the integration of dietary nitrate supplementation as a practical and effec-tive strategy for improving football performance. Given the sport's reliance on anaerobic energy production and rapid acceleration, the use of beetroot supplementation as a natu-ral ergogenic aid presents a promising approach for optimizing athletic conditioning. Fu-ture research should focus on refining supplementation protocols and investigating the long-term implications of dietary nitrates on athletic performance and recovery.

Conclusions

This study provides compelling evidence for the effectiveness of nitrate-rich beetroot supplementation in enhancing anaerobic power, speed-characteristic performance, and explosive leg strength in football players. The results indicate that while structured train-ing alone led to moderate improvements in these performance metrics, the combination of training and dietary nitrate supplementation significantly amplified these gains.

The experimental group, which consumed 500 ml of beetroot juice daily, exhibited superior improvements in peak anaerobic power, minimum anaerobic power, time to reach peak anaerobic power, sprinting speed, speed-specific strength, and explosive leg strength compared to the control group. These findings support the hypothesis that nitrate supplementation enhances oxygen utilization, muscle contractility, and neuromuscular efficiency, leading to improved performance in high-intensity, intermittent sports like football.

From a physiological perspective, the observed improvements can be attributed to in-creased nitric oxide (NO) availability, which enhances vasodilation, mitochondrial effi-ciency, and ATP production, thereby optimizing energy metabolism and muscle function during maximal efforts. The faster sprint times and improved speed-specific strength in the experimental group further reinforce the role of nitrates in facilitating fast-twitch mus-cle fiber activation and phosphocreatine resynthesis.

These findings have important practical implications for sports nutrition and train-ing strategies. Given that football requires repeated short bursts of high-intensity move-ment, integrating nitrate-rich beetroot supplementation into training programs may offer a competitive advantage by improving acceleration, endurance, and power output. Moreo-ver, as a natural and non-pharmacological ergogenic aid, beetroot supplementation pro-vides an alternative to synthetic performance enhancers while supporting sustained ath-letic development and recovery.

While this study presents strong evidence for the ergogenic benefits of dietary ni-trates, several areas warrant further investigation. Future research should explore:

- The long-term effects of nitrate supplementation on muscle adaptation, re-covery, and injury prevention over a competitive season.
- Individual variability in response to dietary nitrates, considering genetic, di-etary, and physiological factors.
- Optimal dosing and timing strategies for nitrate intake to maximize its ergo-genic potential across different athletic populations.
- Comparative analyses with other widely used ergogenic aids, such as caf-feine and creatine, to assess their relative effectiveness.

In conclusion, this study highlights the potential of nitrate-rich beetroot supplemen-tation as a valuable nutritional strategy for enhancing football performance. By improving anaerobic power, speed, and explosive strength, beetroot supplementation can be an inte-gral component of sports conditioning programs. Future studies should focus on opti-mizing supplementation protocols and further exploring its applications in elite sports performance.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

This ensures compliance with ethical research standards and aligns with institutional guidelines. Let me know if you need any modifications!

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