A review of the effects of sodium bicarbonate supplementation on endurance performance

Review Article

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Abstract.

Background In recent times, sodium bicarbonate ($NaHCO_3$) has gained popularity as an ergogenic aid due to its potential to enhance physical performance, reduce muscle fatigue, and support athletes during high-intensity training sessions.

Objectives This systematic review aims to evaluate the efficacy of sodium bicarbonate supplementation in enhancing physical performance, with a particular emphasis on muscular endurance during exercise.

Methods The study employed a Systematic Literature Review (SLR) methodology, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, and utilized the PICO criteria for data selection. Relevant literature was sourced from international databases including Scopus, ScienceDirect, Web of Science (WOS), and PubMed. Search terms used included "Sodium Bicarbonate," "Endurance," "Performance," and "Muscle Fatigue." A total of 9 studies were selected based on their relevance to the topic.

Results Findings suggest that the benefits of sodium bicarbonate supplementation are not universally consistent but rather influenced by multiple factors such as sport type, exercise duration and intensity, the athlete's level of training, and the supplementation protocol (including dosage and timing). Moreover, many studies employed general experimental designs and involved small sample sizes, which limits the broader applicability of the results.

Conclusion The review concludes that sodium bicarbonate supplementation can be effective in enhancing athletic performance, particularly in short- to medium-duration high-intensity activities. Nevertheless, its effectiveness is contingent upon several variables including the nature of the sport, individual fitness level, dosage, and timing of intake. Therefore, a personalized supplementation strategy and further research are essential to maximize its potential benefits.

Keywords: sodium bicarbonate, endurance, performance, muscle fatigue

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INTRODUCTION

In competitive sports, achieving peak performance requires athletes to possess optimal levels of strength, endurance, speed, and recovery capacity [1], [2], [3]. Among these, physical endurance plays a crucial role as a key determinant of athletic performance [4], [5]. Athletes with superior endurance can sustain high-intensity efforts over extended periods, enabling consistent performance throughout training and competition [6], [7], [8]. Therefore, improving physical endurance is a fundamental aspect of performance enhancement in sports [1], [9]. During high-intensity exercise, the body undergoes anaerobic metabolism, leading to the production of lactic acid [10], [11], [12]. This condition arises due to alterations in intracellular and extracellular ion concentrations within muscle cells, ultimately impairing contractile function [13], [14]. The accumulation of lactic acid contributes to performance decline, muscular fatigue, and the sensation of burning in the muscles—factors that inhibit an athlete's capacity to sustain high intensity [15], [16], [17].

As energy metabolism accelerates during training and competition, it leads to the buildup of metabolic by-products such as hydrogen ions (H^+) and inorganic phosphate (Pi) [18], [19]. These metabolites are associated with neuromuscular fatigue—a temporary reduction in the muscle's ability to generate force [20], which directly affects athletic output. Neuromuscular fatigue, stemming from both peripheral (muscular) and central (neural) mechanisms, disrupts contraction efficiency and impedes overall performance [21], [22], [23], [24]. To counteract these physiological limitations, the use of ergogenic aids has gained attention, particularly those aimed at enhancing endurance capacity [25], [26]. Among these, sodium bicarbonate has emerged as a widely adopted supplement for improving performance during high-intensity anaerobic efforts [27], [28]. Functioning as an extracellular buffer, sodium bicarbonate helps neutralize lactic acid by binding excess hydrogen ions (H^+), thus maintaining muscle pH and delaying fatigue [29]. This buffering mechanism not only enhances an athlete's ability to train or compete at high intensities for longer durations but also contributes to the overall resilience of the muscular system against acidosis [30], [31].

Furthermore, sodium bicarbonate supplementation increases systemic blood pH and promotes the efflux of hydrogen ions from muscle tissue into the bloodstream, supporting sustained muscular contractions during intense physical activity [14], [32]. Research has demonstrated its efficacy in enhancing performance during repeated sprint activities, explosive strength training, and prolonged interval sessions [30]. Additionally, this supplement has been associated with improvements in time-to-fatigue and endurance in both individual and team-based sports settings [33].

Based on this comprehensive overview, the present study aims to systematically analyze the effectiveness of sodium bicarbonate supplementation in improving muscle endurance by reviewing findings from existing scientific literature. The contribution of this study lies in consolidating evidence on its physiological impact and practical implications, thereby offering insights into optimizing training and recovery strategies through nutritional intervention.

METHOD

Research Design.

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The analytical framework was adapted from previous bibliometric studies on various topics. This study used the PICO method to identify relevant articles. PICO is a research strategy that utilizes multiple academic sources, including books and scientific journals, to explore the subject of the study. This review focuses on academic literature on the use of sodium bicarbonate supplements in improving muscle endurance.

Search and Selection Strategy.

The databases used in this study include Scopus, ScienceDirect, Web of Science (WOS), and PubMed. The keywords used in the search were sodium bicarbonate, muscle endurance, fatigue, and performance. The inclusion criteria in this study were journal articles discussing using sodium bicarbonate, increasing muscle endurance, reducing fatigue, and performance. Reference management software (Mendeley) was used to organize citations, screen titles, and abstracts and evaluate full-text articles based on PICO selection criteria.

Table 1. PICO Scale

PICO	Inclusion Criteria	Exclusion Criteria
Population	Athletes or physically active individuals aged 18–40 years	Elderly or individuals with certain medical conditions
Interventions	Sodium bicarbonate supplementation at certain doses before or during physical activity	Non-sodium bicarbonate interventions (e.g., caffeine, creatine, or other supplements)
Comparison	Control group, placebo, or other type of intervention compared with sodium bicarbonate	Studies without a comparison group or that do not mention the control method
Outcome	Muscle endurance performance, decreased fatigue, increased exercise capacity	Results unrelated to muscle performance or endurance

Inclusion and Exclusion Criteria.

The search and selection process used electronic databases, including Scopus, ScienceDirect, Web of Science (WOS), and PubMed. The analytical framework applied in this study is consistent with previous studies in the same field. Overall, 1321 articles published between 2018 and 2025 were selected. Reference management software (Mendeley) was used to organize records, screen titles, and abstracts and to review full-text articles on food intake and eating behavior published during the period. Articles were excluded from the study if (1) they only contained abstracts without access to the full text, (2) they were not published in a peer-reviewed scientific journal, (3) they did not open access, or (4) they Did not meet at least one of the inclusion criteria. Only journals that met all inclusion criteria were selected for evaluation. The selection process based on the PRISMA guidelines can be seen in Figure 1.

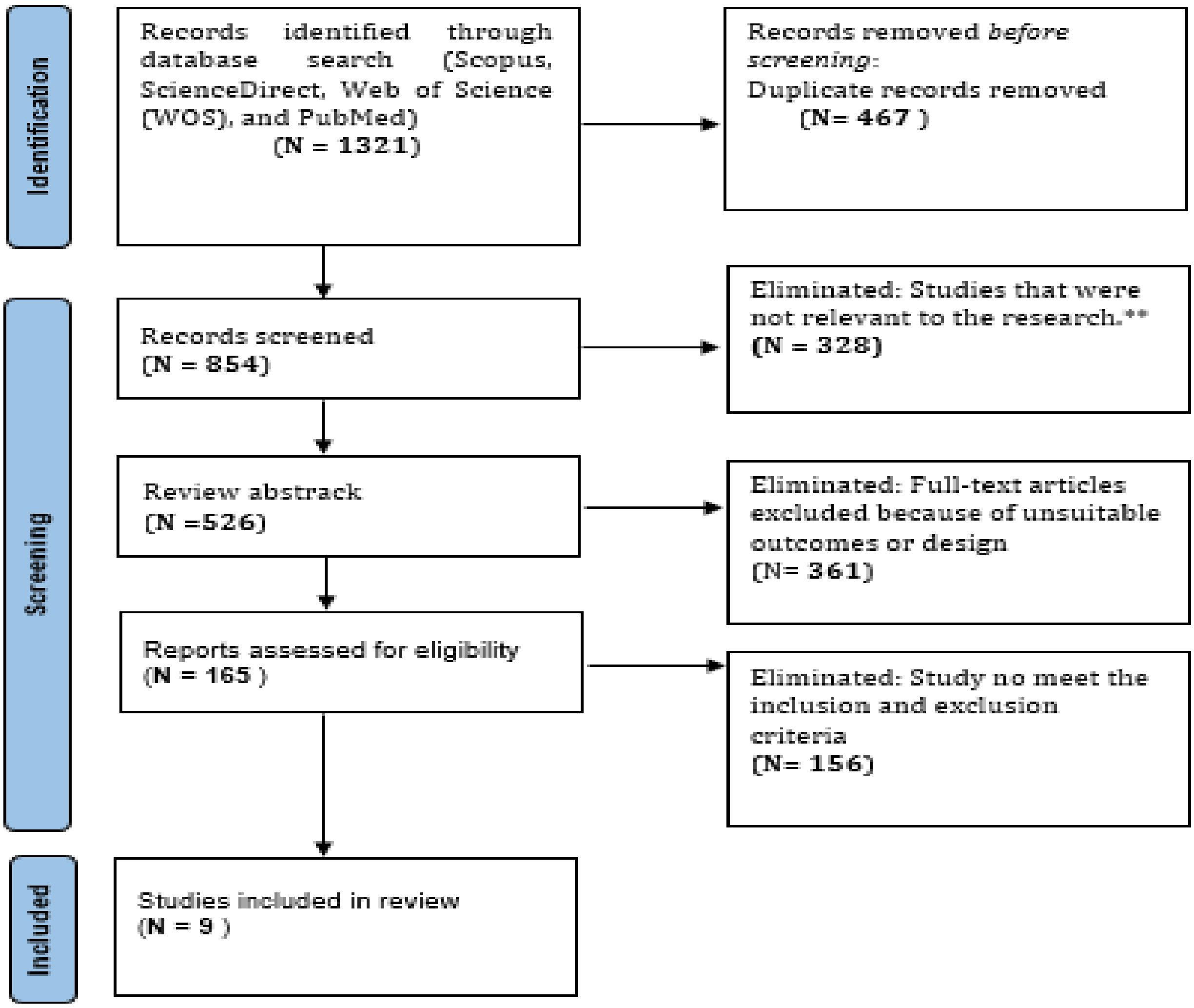

Figure 1. PRISMA Research Flowchart

RESULTS

Table 2. Research findings

Author	Characteristics of the sample	Study Design	Exercise Tes	Supplementation (Type/Doses)	Result
Aktitiz et al., (2024)	12 recreational male cyclists (age: 31.17 ± 4.91 years)	Double-blind, placebo-controlled crossover design	Cycling exercise, in which participants pedaled an ergometer at 95% of a predetermined anaerobic threshold for 30 minutes	acute sodium bicarbonate intake (ASB, 0.2 g kg^{-1} SB)	Acute, multi-day low-dose sodium bicarbonate administration did not significantly improve high-intensity endurance performance in male

					recreational cyclists despite increasing blood bicarbonate concentrations, suggesting limited efficacy for enhancing muscular endurance.
Silva de Souza et al., (2024)	17 partici pants (mean ± SD, age 29 ± 5 years)	Double-blind, placebo-controlled crossover design	Fran Benchmark Test, a CrossFit® exercise consisting of a combination of thrusters and pull-ups with 21-15-9 repetitions, to measure muscle speed and strength. Second, a 500-meter rowing test using a Concept2® ergometer to measure cardiorespiratory endurance.	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Sodium bicarbonate supplementation improved performance in the CrossFit® Fran benchmark, indicating increased muscular endurance. However, it did not significantly affect subsequent 500 m rowing performance, suggesting the benefit may be specific to certain high-intensity exercises rather than all endurance activities.
Newbury et al., (2024)	six highly trained female swimmers (age: 18 ± 1 years)	Double-blind, placebo-controlled crossover design	6 × 75-meter repeated sprint swimming test, followed by a 200-meter maximum time trial after 30 minutes of active recovery	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Consuming sodium bicarbonate (NaHCO3) did not improve performance in highly trained female swimmers, showing no significant improvement in mean 75 m swim time or maximal 200 m swim time, regardless of the consumption strategy used.
Varovic et al., (2023)	Nineteen men who had experience in resistance training	Double-blind Crossover	The training protocol involved three sets of bench press and biceps curl exercises at an intensity of 70% of 1 repetition maximum (1RM) to muscle failure..	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Sodium bicarbonate consumption increased muscular endurance in resistance-trained men, specifically increasing repetitions in the third set and total repetitions in the bench press exercise. This suggests that sodium bicarbonate reduces the effects of acidosis, increasing muscle contractility during resistance training.
LEACH et al., (2023)	Ten trained male cyclists (age, 31.1 ± 9 years)	Double-blind, placebo-controlled crossover design	Participants then performed simulated 16.1-km time trials	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Sodium bicarbonate ingestion before a 16.1 km cycling time trial significantly improved performance times in trained male cyclists, demonstrating its potential as an effective ergogenic aid to enhance endurance

					during prolonged high-intensity exercise.
Lassen et al., (2021)	Twenty-one Danish male and female elite orienteers (age = 25.2 ± 3.6 years)	Double-blind, placebo-controlled crossover design	The athletes also performed two 3.5 km time-trial runs (TT-runs)	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Individualized sodium bicarbonate ($NaHCO_3$) supplementation followed by a warm-up resulted in varying degrees of alkalosis in each athlete, with peak times ranging from 60 to 180 minutes. Supplementation increased alkalosis levels before and after a 3.5 km run and improved athlete performance by an average of 6 seconds, especially in the latter part of the run.
Durkalec-Michalski et al., (2020)	Twenty-four trained male field hockey players	Double-blind, placebo-controlled crossover design	two separate Wingate anaerobic tests (WAnTs).	Acute consumption of sodium bicarbonate (ASB, 0.2 g kg^{-1} SB)	Sodium bicarbonate supplementation, both progressive-chronic and acute, positively influences anaerobic capacity and discipline-specific performance in athletes, especially in field hockey, increasing power indices and buffering capacity during high-intensity efforts, thereby supporting overall athletic performance.
Wang et al., (2019)	Twenty healthy college-age male	Double-blind, placebo-controlled crossover design	The first 3 weeks were at low intensity, and the next 3 weeks were at higher intensity. Blood samples were taken 5 minutes before and 30 minutes after the following HIIT training sessions: week 1 session 1, week 3 session 3, and week 6 session 3.	Consuming 0.3 g/kg body weight of $NaHCO_3$ in capsule form.	Sodium bicarbonate supplementation improves anaerobic performance in athletes by increasing serum HCO3− levels, increasing peak power, and accelerating lactate clearance rates during high-intensity interval training,
Delextrat et al., (2018)	Fifteen female university basketball players (23.3 ± 3.4 years)	Double-blind Crossover	Basketball practice test	Consuming 0.4 g/kg body weight of $NaHCO_3$ in capsule form.	Sodium bicarbonate supplementation significantly improves athlete sprint and repeated jump performance, as demonstrated in female basketball players. It increases mean sprint and circuit times and jump height and

	reduces performance decline without causing gastrointestinal side effects.

DISCUSSION

The use of sodium bicarbonate ($NaHCO_3$) supplementation has long been known as one of the ergogenic agents used to improve sports performance, especially in activities involving the contribution of anaerobic lactate metabolism, where the accumulation of hydrogen ions (H^+) causes a decrease in intramuscular pH which has an impact on muscle fatigue. A review of the various studies in this table reveals that, although there is a consensus regarding the potential of $NaHCO_3$, the results of its application are still diverse and highly dependent on the activity context, protocol design, and individual characteristics of the athlete. One interesting finding emerged from the study of [34], where acute and multi-day $NaHCO_3$ supplementation in recreational cyclists did not significantly impact high-intensity endurance performance despite increasing blood bicarbonate concentrations. This highlights that increasing bicarbonate concentrations is not always directly proportional to increased performance, mainly when the activity is carried out in an intensity zone still dominated by aerobic metabolism. Additionally, the fact that participants were recreational cyclists suggests that individual training level and physiological capacity may be important variables in determining the effectiveness of supplementation.

In contrast to these findings, studies by [27] and [35] showed that in high-intensity, explosive activities such as resistance training and CrossFit®, $NaHCO_3$ supplementation resulted in significant improvements in muscular endurance and final set performance. These findings reinforce the notion that $NaHCO_3$ is most effective when used under conditions that cause high metabolic stress, such as repetitions to muscle failure or short intervals with limited rest. The effects also tend to be more pronounced in the final set or repetition, where H^+ ion accumulation is highest.

A study by [41] extended this evidence to the context of team sports such as basketball, where $NaHCO_3$ was shown to improve sprint and repeated jump performance. These effects occurred without significant gastrointestinal side effects, an important consideration considering that GI complaints are a major limitation of $NaHCO_3$ use, especially at high doses. However, not all studies have shown significant benefits. [36] reported that $NaHCO_3$ did not improve 6×75 m sprint or 200 m time trial performance in elite female swimmers. These findings highlight the variability in response between individuals and the possibility of gender-, sport-or administration-specific responses, which need further exploration. Similarly, [38] showed that peak alkalosis occurred at a highly variable time window (60–180 min), highlighting the need for an individualized approach to supplementation timing. In the context of high-intensity repetitive training (HIIT).

studies by [40] and [39] showed that $NaHCO_3$ increases anaerobic capacity, peak power, and accelerates lactate clearance, which is particularly relevant for athletes who rely on the glycolytic system. These results support its use in sports such as field hockey and HIIT programs, where performance is determined by the ability to sustain high outputs for short, repeated periods. The findings of [37] provide strong evidence that $NaHCO_3$ can improve high-intensity endurance performance in trained male cyclists. This highlights that the response to supplementation is also highly dependent on the population studied, with athletes with higher levels of training likely showing better efficacy due to their more optimal metabolic capacity to exploit the alkalotic environment.

CONCLUSION

It can be concluded that this review confirms that the benefits of $NaHCO_3$ supplementation are not universal but somewhat highly dependent on contextual variables such as type of sport, duration, and intensity of activity, level of training, and supplementation approach (dose and time of administration). However, most studies still use generic designs and limited populations, which limit the generalizability of the findings. In addition, there is still a lack of understanding of physiological biomarkers that can predict the response to $NaHCO_3$ and how they affect training adaptation in the long term. Aspects such as individual buffering capacity, hydration status, and basic nutritional profiles of athletes have also not been widely studied as modulators of the effects of this supplement. Given the differences in results and the complexity of the variables, further research needs to focus on the individualization of supplementation strategies, both in terms of time of administration (peak alkalosis time) and adaptive doses based on gastrointestinal tolerance and body weight. Testing the long-term effects of periodic $NaHCO_3$ use in a structured training program. Evaluation of the effects of $NaHCO_3$ in sports with mixed metabolic characteristics, such as soccer, futsal, or boxing. Exploration of the interaction between $NaHCO_3$ with other supplements, such as beta-alanine or creatine, which also function as buffers.

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Theium bicarbonate supplementation has been proven to improve sports performance, especially in high-intensity and short-medium duration activities. However, its effectiveness highly depends on the type of sport, the athlete's fitness level, the dose, and the proper administration time. An individualized approach and further research are needed to optimize its benefits specifically.

AUTHOR CONTRIBUTION STATEMENT

MH and JDN were responsible for designing and conceptualizing the study, collecting data, and drafting the initial manuscript. UAA, GGM, and ADRA were involved in data collection, results interpretation, and the manuscript's critical revision. SI also acted as the corresponding author, handling all communications and revisions related to the publication.

CONFLICT OF INTEREST AND FUNDING

There is no conflict of interest

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