Sodium bicarbonate supplementation and its impact on endurance performance: A PRISMA-guided systematic review

Review Article

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Abstract.

Background Sodium bicarbonate ($NaHCO_3$) has gained substantial attention as an ergogenic aid due to its buffering capacity, which helps mitigate exercise-induced metabolic acidosis. Its use has been widely explored in high-intensity sports where the accumulation of hydrogen ions contributes to early muscle fatigue and decreased performance.

Objectives This systematic review aims to synthesize current empirical evidence regarding the effectiveness of sodium bicarbonate supplementation in enhancing endurance-related performance outcomes, with a particular focus on its role in delaying muscle fatigue during exercise.

Methods A Systematic Literature Review (SLR) was conducted following the PRISMA guidelines. Article identification and selection employed the PICO framework. Relevant studies were retrieved from Scopus, ScienceDirect, Web of Science, and PubMed using the keywords “sodium bicarbonate,” “endurance,” “performance,” and “muscle fatigue.” Nine peer-reviewed studies met the inclusion criteria and were analyzed descriptively to evaluate the effects of sodium bicarbonate on athletic performance.

Results The findings indicate that sodium bicarbonate supplementation can enhance performance, particularly in high-intensity and short-to-medium-duration activities. However, its effectiveness is highly context-dependent and influenced by exercise modality, duration and intensity, athlete training status, and supplementation protocol—including dosage, timing, and individual physiological tolerance. Several studies employed relatively small and homogeneous samples, limiting the generalizability of the results.

Conclusion Sodium bicarbonate shows consistent potential as an ergogenic supplement for improving endurance-related performance by attenuating metabolic fatigue. Nonetheless, its benefits are not uniform across all athletes or sport types. Optimal outcomes appear to require individualized dosing strategies and sport-specific application. This review provides an updated synthesis of evidence on sodium bicarbonate supplementation and highlights critical variables that moderate its effectiveness. The study underscores the need for individualized supplementation protocols and encourages future research employing larger, more diverse athlete populations and standardized ergogenic assessment methods.

Keywords: sodium bicarbonate, endurance, performance, muscle fatigue.

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INTRODUCTION

Optimal levels of strength, endurance, speed, and recovery capacity are essential for achieving peak performance in competitive sports (Apollaro et al., 2023; Nubatonis et al., 2024; Zamri et al., 2022). Among these components, physical endurance plays a central role in determining an athlete’s overall performance capability (Stepanyan & Lalayan, 2023; Yolanda et al., 2025). Athletes with well-developed endurance are better able to sustain high-intensity performance and maintain efficiency throughout training or competition (Fadilah & Widodo, 2023; Kim & Nam, 2021; Kristiono et al., 2024). Therefore, enhancing endurance is considered a key factor in optimizing athletic performance (Apollaro et al., 2023; Jurić et al., 2019).

High-intensity exercise increases the reliance on anaerobic metabolism, resulting in elevated lactate production (Bachero-Mena & González-Badillo, 2021; Hadjarati & Massa, 2023; Vanderheyden et al., 2020). This metabolic shift alters intracellular and extracellular ion concentrations, ultimately reducing muscle contractile efficiency (Cairns & Renaud, 2023; Kreutzer et al., 2022). The progressive accumulation of lactic acid contributes to performance decline, muscle fatigue, and sensations of muscle burning that impair an athlete's capacity to sustain high-intensity efforts (Gholami, 2023; Rini & Purnomo, 2021; Zagatto et al., 2022). During prolonged or intense activity, energy metabolism accelerates substantially, producing metabolites such as hydrogen ions (H^+) and inorganic phosphate, both of which exacerbate fatigue (Malone et al., 2021; Raeder et al., 2024).

Accumulation of these metabolites is closely linked to neuromuscular fatigue, defined as a temporary reduction in the muscle's ability to generate force, driven by both peripheral and central mechanisms (Badaruddin et al., 2023; Dalton et al., 2024). Such fatigue diminishes muscle contractile capacity and compromises performance during demanding training or competition (Abdulkader et al., 2024; Sundberg et al., 2018). As a result, strategies to mitigate metabolic acidosis and attenuate neuromuscular fatigue have become a critical focus for athletes and sports practitioners.

In recent years, the use of ergogenic supplements aimed at improving endurance has gained substantial popularity (Katmawanti et al., 2022; Miguel-Ortega et al., 2024). Sodium bicarbonate has emerged as one of the most widely adopted buffering agents, particularly in sports characterized by repeated high-intensity efforts and substantial anaerobic contributions (Gurton et al., 2024; Varovic et al., 2023). Functioning as an extracellular buffer, sodium bicarbonate helps neutralize excess hydrogen ions, thereby attenuating the decline in muscle pH associated with fatigue (Hanada et al., 2023). By increasing blood pH and reducing hydrogen ion concentration, sodium bicarbonate supplementation delays fatigue and supports sustained performance during high-intensity activity (Insam & Chidley, 2024; Ragone et al., 2020; Kreutzer et al., 2022). Additionally, it facilitates the efflux of H^+ ions from muscle cells into the bloodstream, enabling muscles to maintain contraction efficiency during repeated bouts of intense exercise (Grgic et al., 2021).

Current evidence indicates that sodium bicarbonate can enhance performance in various high-intensity exercise modalities, including repeated sprints, explosive efforts, and interval-based training (Insam & Chidley, 2024). It has also been shown to extend time to fatigue across both individual and team sports, underscoring its potential as a practical ergogenic aid (Lopes-Silva & Franchini, 2021). Based on these considerations, this study aims to examine the effectiveness of sodium bicarbonate supplementation in enhancing muscle endurance by synthesizing findings from previous empirical research.

METHOD

Search and Selection Strategy

Four major electronic databases were searched: Scopus, ScienceDirect, Web of Science (WOS), and PubMed. The search was conducted using combinations of the following keywords: sodium bicarbonate, muscle endurance, fatigue, and performance. The inclusion criteria focused on journal articles addressing sodium bicarbonate supplementation, enhancement of muscle endurance, reduction of fatigue, and improvement in exercise performance. Reference management software (Mendeley) was used to organize citations, remove duplicates, screen titles and abstracts, and assess full-text eligibility based on PICO criteria.

Table 1. PICO Criteria

PICO	Inclusion Criteria	Exclusion Criteria
Population	Athletes or physically active individuals aged 18–40 years	Elderly individuals or participants with medical conditions
Intervention	Sodium bicarbonate supplementation administered before or during physical activity	Non–sodium bicarbonate interventions (e.g., caffeine, creatine, other ergogenic aids)
Comparison	Control group, placebo, or alternative intervention compared with sodium bicarbonate	Studies lacking a comparison group or control method
Outcome	Muscle endurance performance, reduced fatigue, increased exercise capacity	Outcomes unrelated to muscle endurance or performance

Inclusion and Exclusion Criteria

The literature search and selection process strictly adhered to PRISMA procedures and was conducted across Scopus, ScienceDirect, Web of Science, and PubMed. The analytical framework used in this review aligns with prior studies in the same domain. A total of 1,321 articles published between 2018 and 2025 were initially retrieved. All records were imported into Mendeley for organization, duplicate removal, and systematic screening of titles, abstracts, and full-texts.

Articles were excluded if they met any of the following conditions:

1. The full text was unavailable (abstract-only publications).
2. The article was not published in a peer-reviewed scientific journal.
3. The article did not provide open access.
4. The article failed to meet at least one of the PICO inclusion criteria.

Procedure

Only studies that satisfied *all* inclusion parameters were retained for detailed evaluation. The complete selection process, including identification, screening, eligibility assessment, and final inclusion, is illustrated in Figure 1, following PRISMA guidelines.

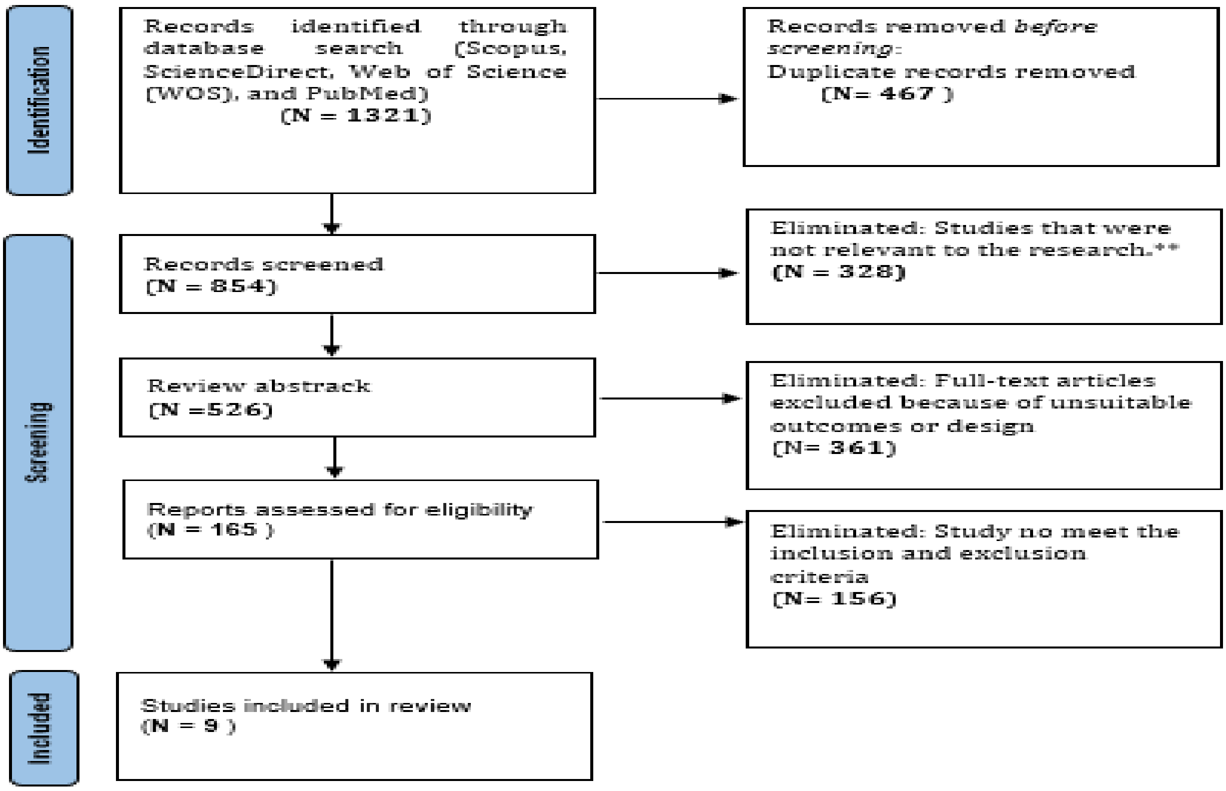

Figure 1. PRISMA Research Flowchart

RESULTS AND DISCUSSION

Results

The study began with the collection of baseline data on the aerobic endurance (VO_2max) of handball players from the Sambas district team. Following this initial assessment, the athletes completed a structured circuit training program integrated into their regular training regimen. At the end of the intervention, VO_2max was reassessed to determine changes relative to the pretest results. These data were subsequently compared to evaluate the effect of the circuit training intervention. A total of nine studies that met the inclusion criteria were analyzed to evaluate the effects of sodium bicarbonate supplementation on muscular endurance, fatigue reduction, and overall exercise performance. Overall, the evidence demonstrates mixed outcomes, with several studies reporting performance improvements while others found no measurable benefit.

Acute sodium bicarbonate ingestion at doses ranging from 0.2 to 0.4 $g{\cdot}kg^{-1}$ produced varying physiological and performance responses across different exercise modalities. For instance, Aktitiz et al. (2024) reported that acute, multi-day low-dose supplementation (0.2 $g{\cdot}kg^{-1}$) did not significantly improve high-intensity cycling performance in recreational cyclists, despite increases in blood bicarbonate levels. Similarly, Newbury et al. (2024) found no enhancement in repeated sprint swimming or maximal 200 m performance among highly trained female swimmers following 0.3 $g \cdot kg^{-1}$ supplementation. Conversely, several studies demonstrated notable performance gains. Silva de Souza et al. (2024) observed improved muscular endurance during the CrossFit® Fran benchmark test after consuming 0.3 $g \cdot kg^{-1}$ sodium bicarbonate, although no benefit was seen in the subsequent 500 m rowing event, suggesting task-specific effects. Varovic et al. (2023) also reported enhanced repetitions to failure in resistance-trained men, particularly during bench press exercises, indicating improved buffering capacity and reduced acidosis during high-intensity resistance training.

Performance enhancement was consistently observed in endurance-focused tasks. Leach et al. (2023) showed that trained male cyclists experienced significantly faster times in a simulated 16.1 km time trial following 0.3 $g \cdot kg^{-1}$ supplementation. Lassen et al. (2021) further demonstrated that individualized sodium bicarbonate timing improved alkalosis and reduced time-trial duration by an average of six seconds among elite orienteers, particularly during the latter stages of the run. Research involving anaerobic performance also supports positive effects. Durkalec-Michalski et al. (2020) found that both progressive-chronic and acute 0.2 $g \cdot kg^{-1}$ supplementation improved anaerobic capacity and sport-specific performance indicators in trained male field hockey players. Similarly, Wang et al. (2019) reported increases in serum bicarbonate, peak power, and lactate clearance during high-intensity interval training after supplementation with 0.3 $g \cdot kg^{-1}$ sodium bicarbonate.

Finally, Delextrat et al. (2018) demonstrated significant improvements in sprinting, repeated jumping performance, and fatigue resistance among female basketball players following 0.4 $g \cdot kg^{-1}$ ingestion, without notable gastrointestinal side effects. These findings highlight the potential of sodium bicarbonate to enhance repeated high-intensity efforts in team sports. Taken together, the reviewed studies indicate that the ergogenic effects of sodium bicarbonate are influenced by several factors, including dosing strategy, exercise modality, athlete training status, and event-specific metabolic demands. While positive effects are consistently observed in many high-intensity and anaerobic tasks, several studies show no benefit, suggesting that individual variability and exercise-specific responses must be considered.

Discussion

The use of sodium bicarbonate ($NaHCO_3$) supplementation has long been recognized as an ergogenic strategy to enhance sports performance, particularly in activities that rely heavily on anaerobic glycolysis where the accumulation of hydrogen ions (H^+) reduces intramuscular pH and contributes to muscle fatigue. The review of studies included in this analysis demonstrates that, although there is a general consensus on the physiological potential of $NaHCO_3$, its ergogenic effects remain inconsistent and are strongly influenced by exercise modality, supplementation protocol, and individual athlete characteristics.

One notable observation arises from the findings of Aktitiz et al. (2024), who reported that acute and multi-day $NaHCO_3$ supplementation did not significantly enhance high-intensity cycling performance in recreational athletes, despite elevating blood bicarbonate levels. This result indicates that increased extracellular buffering capacity does not necessarily translate into improved performance when the exercise intensity is still predominantly aerobic. Furthermore, the recreational training status of participants highlights the possibility that individuals with lower physiological conditioning may have limited ability to fully utilize the alkalotic environment created by supplementation.

In contrast, studies involving high-intensity, metabolically demanding activities—such as those by Varovic et al. (2023) and Silva de Souza et al. (2024)—demonstrated meaningful improvements in muscular endurance and final-set performance following $NaHCO_3$ ingestion. These findings strengthen the premise that $NaHCO_3$ provides the greatest benefit during tasks characterized by high levels of metabolic stress, including repetitions to failure and short-interval efforts with minimal recovery. The ergogenic effect also tends to become more pronounced during later stages of exercise, when H^+ accumulation reaches its peak.

The study by Delextrat et al. (2018) further expands this evidence to team-based sports, showing that $NaHCO_3$ supplementation improves sprint ability and repeated jump performance in basketball players. Importantly, these benefits occurred without significant gastrointestinal discomfort—a common limitation of bicarbonate supplementation. Nevertheless, inconsistent findings also persist. For example, Newbury et al. (2024) found no improvements in repeated sprint swimming performance or maximal 200 m efforts among elite female swimmers, emphasizing the presence of individualized or sport-specific responses that require deeper investigation. Likewise, Lassen et al. (2021) identified substantial variability in peak alkalosis timing (60–180 minutes), underscoring the necessity for individualized dosing schedules to optimize ergogenic outcomes.

In the context of high-intensity interval exercise, studies by Wang et al. (2019) and Durkalec-Michalski et al. (2020) confirmed that $NaHCO_3$ enhances anaerobic capacity, increases peak power output, and accelerates lactate clearance—benefits that are particularly relevant for athletes relying on the glycolytic energy system. These adaptations are consistent with the mechanistic role of $NaHCO_3$ as an extracellular buffer that delays the onset of metabolic fatigue. Moreover, the findings of Leach et al. (2023) provide compelling evidence that $NaHCO_3$ can significantly improve high-intensity endurance cycling performance in well-trained athletes, suggesting that individuals with higher fitness levels may respond more favorably to supplementation due to their superior metabolic efficiency and ability to exploit enhanced buffering capacity.

Overall, this review confirms that the ergogenic impact of $NaHCO_3$ supplementation is far from universal, being shaped by exercise type, duration, intensity, training status, and protocol specificity (dose and timing). Despite substantial evidence supporting its benefits, many studies still employ general supplementation designs and involve relatively homogeneous samples, limiting the broader applicability of results. Additionally, there is limited understanding of the physiological biomarkers that may predict responsiveness to $NaHCO_3$, as well as how supplementation interacts with long-term training adaptations. Variables such as individual buffering capacity, hydration status, and baseline nutritional profiles remain understudied despite their potential influence on efficacy.

CONCLUSION

This systematic review confirms that sodium bicarbonate supplementation can enhance exercise performance, particularly in activities characterized by high intensity and short-to-moderate duration, where metabolic acidosis is a primary limiting factor. The effectiveness of supplementation, however, is not universal; it varies substantially depending on the type of sport, the athlete's training status, the administered dose, and the timing relative to exercise. Evidence consistently shows that sodium bicarbonate yields the greatest benefits in tasks that elicit high glycolytic demand and rapid hydrogen ion accumulation, whereas its effects are less pronounced in predominantly aerobic activities or in populations with lower physiological conditioning. Given the wide inter-individual variability observed across studies, an individualized supplementation strategy—considering peak alkalosis timing, gastrointestinal tolerance, and body mass—appears essential for maximizing ergogenic outcomes. Future research should focus on identifying physiological predictors of responsiveness, optimizing dosing protocols, examining long-term adaptation within structured training programs, and exploring interactions with other buffering agents. Such efforts are needed to refine evidence-based guidelines and ensure the safe, effective, and sport-specific application of sodium bicarbonate supplementation.

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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.

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