El efecto de una bebida de bicarbonato de sodio en la recuperación de la fatiga anaeróbica y del ácido láctico después del ejercicio extenuante

The Effect of a Sodium Bicarbonate Drink on the Recovery of Anaerobic Fatigue and Lactic Acid After Exhausting Exercise

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Abstract

Introduction: Sodium bicarbonate ($NaHCO_3$) is an ergogenic agent that enhances the body's buffer capacity and reduces fatigue from lactic acid accumulation during anaerobic exercise. However, its effectiveness in intermittent sports like badminton is limited, necessitating further research.
Objective: This research aims to assess the impact of sodium bicarbonate intake on alleviating anaerobic fatigue and lowering lactic acid concentrations after strenuous exercise.
Methodology: The study involved 36 male badminton players from the Indonesian Badminton Association (PBSI) Jombang, divided into two groups: the treatment group (Sb) and the control group (Pla). Before the test, the Sb group consumed sodium bicarbonate solution to mitigate adverse effects, while the Pla group took mineral water. Participants engaged in anaerobic exercise, jogging at 95% of their heart rate. They were assessed using the RAST and Roche Cobas Accutrend Plus for lactic acid concentrations.
Results: The study found that sodium bicarbonate intake significantly reduced the rise in fatigue index and lactic acid concentrations compared to the control group. The control group experienced a mean increase of 3.658 ± 1.87 watts/s, while the treatment group showed a decrease of only 1.791 ± 1.65 watts/s.
Discussion: Sodium bicarbonate consumption significantly reduced the increase in fatigue index and lactic acid levels after anaerobic exercise, supporting its role as an effective strategy in maintaining badminton athlete performance.
Conclusions: Sodium bicarbonate stabilizes body pH by neutralizing lactic acid and H^+ ions, reducing metabolic acidosis during intense anaerobic exercise. It may help reduce anaerobic fatigue in badminton athletes, but further studies are needed.

Keywords

Sodium Bicarbonate; Recovery; Anaerobic fatigue; Lactic acid; Exhausting exercise

Resumen

Introducción: El bicarbonato de sodio ($NaHCO_3$) es un agente ergogénico que mejora la capacidad amortiguadora del cuerpo y reduce la fatiga causada por la acumulación de ácido láctico durante el ejercicio anaeróbico. Sin embargo, su eficacia en deportes intermitentes como el bádminton es limitada, por lo que se requiere más investigación.
Objetivo: Esta investigación busca evaluar el impacto de la ingesta de bicarbonato de sodio en el alivio de la fatiga anaeróbica y la reducción de las concentraciones de ácido láctico después del ejercicio extenuante.
Metodología: El estudio involucró a 36 jugadores de bádminton masculinos de la Asociación Indonesia de Bádminton (PBSI) en Jombang, divididos en dos grupos: el grupo de tratamiento (Sb) y el grupo de control (Pla). Antes de la prueba, el grupo Sb consumió una solución de bicarbonato de sodio para mitigar los efectos adversos, mientras que el grupo Pla tomó agua mineral. Los participantes realizaron ejercicio anaeróbico, trotando al 95 % de su frecuencia cardíaca. Se evaluaron las concentraciones de ácido láctico mediante el RAST y el cuestionario Cobas Accutrend Plus de Roche.
Resultados: El estudio reveló que la ingesta de bicarbonato de sodio redujo significativamente el aumento del índice de fatiga y las concentraciones de ácido láctico en comparación con el grupo control. El grupo control experimentó un aumento medio de 3,658 ± 1,87 vatios/s, mientras que el grupo de tratamiento mostró una disminución de tan solo 1,791 ± 1,65 vatios/s.
Discusión: El consumo de bicarbonato de sodio redujo significativamente el aumento del índice de fatiga y los niveles de ácido láctico tras el ejercicio anaeróbico, lo que respalda su papel como estrategia eficaz para mantener el rendimiento de los atletas de bádminton.
Conclusiones: El bicarbonato de sodio estabiliza el pH corporal neutralizando el ácido láctico y los iones H^+, reduciendo la acidosis metabólica durante el ejercicio anaeróbico intenso. Podría ayudar a reducir la fatiga anaeróbica en atletas de bádminton, pero se necesitan más estudios.

Palabras clave

Bicarbonato de sodio; Recuperación; Fatiga anaeróbica; Ácido láctico; Ejercicio agotador

Introduction

Badminton is a popular sport in Indonesia that has a high intensity and intermittent character (short rest intervals, jumping movements, fast changes of direction, lunges, and strong arm power) (Wee et al., 2017). Badminton is a racket sport characterized by short and quick multi-directional motions (Phomsoupha and Laffaye, 2015; Sturgess and Newton, 2008). This sport necessitates players to execute five motions, including altering direction, rotating and extending, and lunging, in reaction to their adversary's stroke, with the shuttlecock traveling at velocities ranging from 50 to 70 meters per second (110 to 155 miles per hour) (Ooi *et al.*, 2009; Kuntze, Mansfield and Sellers, 2010; Wiriawan *et al.*, 2024). This sport requires players to perform repeated explosive actions in a short duration, making anaerobic endurance a critical factor in maintaining performance during the match. This activity depletes phosphagen energy stores and relies on anaerobic glycolysis, which results in the accumulation of lactic acid as a byproduct.

High-intensity sports training, like badminton, results in lactic acidosis, a decrease in sarcoplasmic pH and an increase in H+ concentration (Forbes et al., 2020; Siegler et al., 2016a). During hard exercise, lactic acid and H+ ions build up in the muscles, which lowers the pH and leads to metabolic acidosis. This makes muscles tired, weaker, and less able to coordinate their movements (Rusdiawan et al., 2020; Chycki et al., 2018).. This condition has the potential to reduce the player's ability to maintain speed, accuracy, and response precision during the match (Siegler et al., 2016a). In his research, Rusdiawan & Habibi (2020) also stated that an increase in lactic acid would lead to an increase in the anaerobic fatigue index. According to some researchers, the accumulation of lactic acid causes muscle fatigue that occurs when intensive exercise is taking place (Septiani et al., 2010). This can reduce an athlete's performance and threaten it. To maintain athlete performance in the face of acidosis conditions caused by exercise, one strategy is to consume sodium bicarbonate (NaHCO3) (Zhou et al., 2022). Sodium bicarbonate (NaHCO3) is an ergogenic aid by inducing an increase in extracellular bicarbonate that will significantly increase the buffering capacity of endogenous bicarbonate (Hilton et al., 2019). Consuming sodium bicarbonate will accelerate the neutralization of lactate and H+ from muscle cells into the circulation so that the pH tends to be normal and supports metabolic processes in the body (Bishop et al., 2007).

Several studies have evaluated the effects of sodium bicarbonate ($NaHCO_3$) as an ergogenic supplement to counteract acidosis (Krustrup et al., 2015a; Miller et al., 2016). Studies in sports such as cycling, running, and swimming have shown that $NaHCO_3$ can increase the body's buffer capacity, reduce the increase in lactic acid, and delay the onset of fatigue (Dalle et al., 2021; Driller et al., 2012; Durkalec-Michalski et al., 2018; Lindh et al., 2008; Pruscino et al., 2008). However, the results are inconsistent, with some studies reporting no significant impact on performance, especially when the dose or timing of administration is not optimal (Ragone et al., 2020; Zhou et al., 2022). This variation suggests that the effectiveness of $NaHCO_3$ may depend on the type of sport, intensity, and supplementation protocol (Grgic et al., 2021).

Despite the unique anaerobic demands of badminton, research on the utilization of $NaHCO_3$ in this context is limited. The majority of previous studies have focused on cyclic sports such as running or cycling, while sports with complex and intermittent movement patterns such as badminton have not been adequately explored (Wee et al., 2017). This lack of information makes it harder to come up with specific supplementation suggestions for badminton players, even though buffers may be more important to prevent acidosis because the game is so unpredictable (Wiriawan *et al.*, 2024)

This study sought to assess the impact of $NaHCO_3$ ingestion on anaerobic fatigue recovery and post-exercise lactate concentrations in badminton athletes. The purpose of this study is to provide real-world evidence on how well $NaHCO_0$ works as a dietary supplement to improve anaerobic endurance and speed up recovery. The study will gradually administer a dose of 0.4 g/kg body weight to prevent stomach problems (Krustrup et al., 2015b). These findings are pertinent to coaches and athletes in refining supplementing strategies and facilitating the creation of more efficacious sports nutrition products for high-intensity sports like badminton (Burke, 2013)

Method

Participants

The research study included a cohort of 36 Jombang Badminton Association (PBSI) athletes that met the following criteria: male, aged between 16 and 20 years, having a normal weight and BMI, Minimum 7 years of training experience, has won at least district or city level, and willingly accepted to participate in the study while adhering to all the protocols. Long-term athletes with extensive training experience (> 7 years) have stable physiological adaptations to intensive anaerobic training, such as increased intramuscular buffer capacity, glycolytic efficiency, and acidosis tolerance (Ooi et al., 2009; Phomsoupha & Laffaye, 2015). This reduces variability in individual responses to supplements, making study results more reliable (Wee et al., 2017). Competitive experience ensures homogeneous fitness and technical skills, affecting the ability to consistently undergo exhaustive training protocols. Elite or sub-elite athletes have a structured training pattern, making the physiological response to supplements more predictable (Sturgess & Newton, 2008).

Prior to the study, all volunteers were provided with comprehensive information regarding the research objectives, methodologies, and any potential adverse effects that could arise as a result. The chosen research sample was given informed consent to indicate their voluntary decision to participate in the study. The research sample was subsequently separated into two cohorts (Pla and Sb), each consisting of 18 individuals, using the ordinal pairing technique.

Procedure

The lactic acid levels were tested using a lactic meter called Roche Cobas Accutrend Plus GCTL Metre. Before the lactic meter is used, the strip is calibrated by inserting it into the lactose test inlet strip. After the calibration strip is inserted, the F-7 appears on the screen, meaning the device is in normal condition. After the calibration process, the middle finger from which blood will be taken is cleaned with alcohol. The blood sample is taken by pressing the softclick that has been filled with a needle. The blood that comes out of the glass is attached to the test strip (the tip of the circle) so that the blood is "sucked up" by the test strip. After a few seconds, the blood lactic acid level will appear on the screen.

The anaerobic fatigue index was measured using the RAST Test (Running-based Anaerobic Sprint Test) (Mackenzie, 1998) during two data collection sessions: a pretest and a posttest. The RAST test was conducted by performing six repeats of a 35-meter sprint, with a 10-second rest period between each repetition. The time at which the act of running is documented six times. Next, determine the speed by dividing the distance travelled by the time taken. Calculate the acceleration by dividing the speed by the time. Find the force by multiplying the body weight by the acceleration. Finally, calculate the power by multiplying the force by the speed. Compute the fatigue index using the RAST Calculator:

$$\text{Fatigue index} = \frac{\text{Maximal Power} - \text{Minimal Power}}{\text{Total time of 6 sprints}}$$

The participants exclusively sipped mineral water for a duration of 8 hours before to undertaking the pretest. The study evaluated the respondent's health state, including their pulse rate and blood pressure. The research further examined the respondents' eating habits, medical history, and their most recent physical activity during the three days before the pretest. Thirty minutes after the pretest, participants in the treatment group (Sb) swallowed a sodium bicarbonate solution at a dose of 0.4 grams per kilogram of body weight, while the placebo group (Pla) consumed mineral water (Krustrup et al., 2015b). 500 cc of water solubilizes sodium bicarbonate (Hartono & Sukadiono, 2017). We supplied sodium at three consecutive periods of 60 minutes, 45 minutes, and 30 minutes to prevent emesis. Bicarbonate solution is given at three different times to ensure gradual acid neutralization during exercise, maintaining stable blood pH (Hilton et al., 2019; Krustrup et al., 2015b). The optimal time for metabolic alkalosis is 60 to180 minutes post-consumption, depending on the dose and individual (Hilton et al., 2019; Krustrup et al., 2015b). High doses of $NaHCO_3$ can trigger gastrointestinal symptoms due to stomach irritation and CO_2 gas release (Ragone et al., 2020; Zhou et al., 2022). Split-dose administration reduces these symptoms and allows the body to adapt to the gradual increase in bicarbonate (Krustrup et al., 2015b). Perform high-intensity anaerobic exercise 30 minutes after the last consumption to ensure the blood bicarbonate concentration peaks at the beginning of exercise (Siegler et al., 2016a). Synchronizing supplementation and physical activity timing is crucial for maximizing ergogenic benefits (Hilton et al., 2019)

After 60 minutes, the trial participants had either a sodium bicarbonate solution or mineral water. They next performed anaerobic activities by jogging on a treadmill at an intensity of 95% of their maximum heart rate (Shi et al., 2019). The RAST test evaluated the anaerobic fatigue index of the study participants 30 minutes after anaerobic exercise.

Data analysis

Data were analyzed with statistical software and were presented as mean values and standard deviation (SD). Paired t-test was performed to compare fatigue index before and after sodium bicarbonate administration. Independent t-test was performed to compare between groups. The tests were all two-tailed and p<0,05 was considered statistically significant.

Results

A total of thirty-six badminton athletes took part in this study. The characteristics of the research subjects are presented in table 1.

Table 1. Characteristics of research subjects

Group	Mean±SD				
	Age (years)	Body height (cm)	Body weight (kg)	BMI	Training experience (Years)
Pla	17.56±1.29	168.89±2.81	60.56±3.85	21.22±0.94	7.56±0.78
Sb	18.44±1.25	167.00±4.56	63.00±3.85	22.61±1.40	7.50±0.51

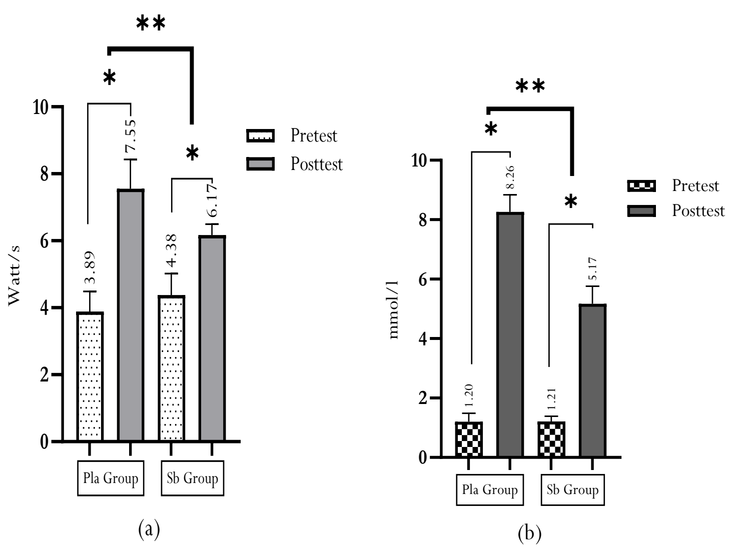
Table 1 shows the results in accordance with the research criteria, specifically the age range of 17-20 years and those with a normal BMI (18.5-24.9). In Indonesia, 17- to 18-year olds are included in the cadet age group (towards the senior age group). To find out the difference between the rates of fatigue of the Pla and Sb groups, we presented the difference table below.

Table 2. Impact of anaerobic exercise and sodium bicarbonate administration on fatigue index and lactic acid alterations

Group		Mean±SD		p-value	Mean±SD		p-value
		Fatigue index	Δ Fatigue index		Lactic acid	Δ Lactic acid	
Pla	Pre	3,89±1,20	-3,658±1,87*	0,003**	1,20±0,57	-7,061±1,31*	0,000**
	post	7,55±1,77			8,26±1,16		
Sb	Pre	4,38±1,29	-1,791±1,65*		1,21±0,35	-3,961±1,17*	
	Post	6,17±0,66			5,17±1,19		

*significant difference between pre and post (p≤0.05); **significant difference between Pla and Sb group (p≤0.05).

Fig 1. The changes in (a) Fatigue index, and (b) lactic acid after being given sodium bicarbonate; *significant difference between pre and post;



**significant difference between Pla and Sb group (p≤0.05).

Table 2 shows that the Pla and Sb groups had a significant increase in the fatigue index and lactic acid (p<0,05) after anaerobic exercise, but the Pla group had a sharper increase in fatigue and lactic acid. To determine the difference between the effect of NaHCO3 administration to the fatigue index and lactic acid, the differences between pre- and post-data on the Pla group and the Sb group are calculated using the independent sample t test. Before calculating the independent sample t test, it is necessary to know the rate of difference in the influence of administering NaHCO3 against the Pla and Sb groups.

Figure 1 illustrates the disparities in pre-post fatigue index and lactic acid measurements between the bigger Pla group and the Sb group. We conduct an independent sample t-test to statistically ascertain the difference. The results of the independent sample t-test showed a significant difference between the Pla and Sb groups in both the fatigue index and lactic acid levels during anaerobic activity, with the fatigue index value being $p = 0.003$ and the lactic acid value being $p = 0.000$. Consequently, it may be deduced that the administration of $NaHCO_3$ influences the tiredness index and lactic acid levels post-anaerobic exercise.

The difference in the fatigue index increase between the Pla and Sb groups had an effect size of $d = 1.06$, which is quite large. This showed that giving $NaHCO3_0$ significantly decreased the buildup of anaerobic fatigue, as shown by both clinical and statistical evidence. In a practical context, athletes who consumed $NaHCO_3$ experienced a 53% lower increase in fatigue compared to the placebo group ($\Delta Sb = 1.791$ vs. $\Delta Pla = 3.658$). In addition, the difference in lactic acid levels between the two groups had an effect size of $d = 2.5$, which was very large, indicating that $NaHCO_3$ not only reduced the increase in lactic acid statistically but also had a real physiological impact. The increase in lactic acid was 44% lower in the Sb group than in the Pla group ($\Delta Sb = 3.961$ vs. $\Delta Pla = 7.061$). This directly supported the idea that $NaHCO3_0$ could reverse metabolic acidosis.

Discussion

Exercise at 95% of maximal heart rate is anaerobic activity (Ito, 2019). Anaerobic exercise is a high-intensity, short-duration activity that digests an energy source without oxygen (Patel et al., 2017). The ATP-PC system and anaerobic glycolysis derive energy during anaerobic exercise, yielding less ATP than the aerobic system and resulting in lactic acid generation (Wasserman, 1986; Mancha-Triguero et al., 2020). Examples of anaerobic sports include weightlifting, cycling competitions, and sprints (Manansang et al., 2018; Hecksteden et al., 2015). The metabolism of anaerobic exercise results in the generation of lactic acid in the engaged muscles. The bloodstream discharges a portion of the generated lactic acids, causing a decrease in blood pH and disrupting the acid-base equilibrium (Rusdiawan et al., 2020; Chycki et al., 2018).

This study provides important insights into the potential of sodium bicarbonate as an ergogenic supplement to enhance athlete performance in high-intensity, intermittent sports such as badminton. Lactic acid is a tricarboxylic biomolecule with both a carboxyl group and a hydroxyl group. Hidayah (2018) explained that lactic acid is the final result of the anaerobic glycolysis process generated by erythrocytes and active myocytes. Lactic acid is sufficiently powerful to dissociate into lactate and H+ ions. The increase of H+ ions will decrease the pH and induce acidosis (Westerblad et al., 2002).

The production of lactic acid, which causes the release of protons and the formation of the acid salt sodium lactate, explains the discussion of acidosis during intense exercise. This biochemical event is referred to as lactic acidosis (Shalayel & Ahmed, 2010). Another theory suggests that acidosis is not the only factor that decreases the contraction velocity observed during fatigue (Theofilidis et al., 2018).

The reduction in lactic acid levels and reduced tiredness index in the sodium bicarbonate group suggest that sodium bicarbonate aids in stabilizing body pH during vigorous exercise, thus enhancing muscular endurance and alleviating fatigue. This corroborates with research indicating that sodium bicarbonate enhances athletic performance by expediting the neutralization of lactic acid in the body (Rusdiawan et al., 2020). Nonetheless, despite the favorable outcomes, several additional research studies indicate varied impacts contingent upon the kind of exercise and its intensity (Hadzic et al., 2019). Further research is necessary to determine the appropriate dosage and duration of sodium bicarbonate administration.

Researchers have examined sodium bicarbonate for its ability to improve anaerobic workout performance. Sodium bicarbonate, often known as baking soda, serves as a buffering agent that helps mitigate the accumulation of lactic acid in muscles during high-intensity exercise, thereby postponing the onset of tiredness (Burke, 2013; Shelton et al., 2010; Siegler et al., 2016b). The ergogenic benefits of sodium bicarbonate on anaerobic performance are well established, but its influence on post-exercise recovery remains ambiguous. Research indicates that sodium bicarbonate could hasten the replenishment of muscle glycogen reserves and enhance future exercise performance, yet the underlying mechanisms remain incompletely comprehended (Shelton et al., 2010; Siegler et al., 2016b).

Studies on intermittent sports, such as cycling sprints and team sports, consistently report ergogenic benefits from $NaHCO_3$. Krustrup et al. (2015b) observed a 6.5% improvement in repeated sprint performance among trained football players using a split-dose protocol (0.4 g/kg, administered at 90, 60, and 30 minutes pre-exercise). Dalle et al. (2021) discovered that cyclists' peak power output went up by 4.2% when they used $NaHCO_3$ during a 30-second Wingate test. This was because it made the buffering of H+ ions better. In contrast, several studies report minimal or no ergogenic effects: In a study by Zhou et al. (2022), recreationally active males who took enteric-coated $NaHCO_3$ did not significantly improve their anaerobic performance (e.g., 30-second Wingate test). This was true even though they were given the same dose (0.3 g/kg). Ragone et al. (2020) observed no performance benefits in jiu-jitsu athletes, with 30% reporting gastrointestinal (GI) discomfort, potentially masking any ergogenic effects. These differences in results are likely due to several causes: (1) The efficacy of $NaHCO_3$ appears context-dependent, with greater benefits in sports requiring repeated anaerobic bursts (e.g., badminton, football) versus continuous or skill-based activities (e.g., jiu-jitsu) (Grgic et al., 2021). The short rallies and frequent changes of direction in badminton make lactic acid build up quickly. This creates a physiological "buffer gap" that can be filled by NaHCO3 (Phomsoupha & Laffaye, 2015). However, when doing steady-state or mixed aerobic and anaerobic activities, acidosis may not play as big of a role in fatigue, which means that $NaHCO_0$ may not have as much of an effect (Zhou et al., 2022). (2) The split-dose regimen (60, 45, and 30 minutes pre-exercise) used in the current study likely optimized plasma alkalosis while minimizing GI distress. In contrast, single-dose protocols (e.g., Zhou et al., 2022) or delayed-release formulations may fail to synchronize peak buffering capacity with exercise onset, reducing efficacy (Hilton et al., 2019). GI side effects, which were reported in 25–30% of people who took part in other studies (Ragone et al., 2020), could further mess up the results by indirectly making people less productive. (3) Elite athletes, such as those in the current study, exhibit enhanced innate buffering capacity due to long-term anaerobic training adaptations (Siegler et al., 2016a). In a strange way, this may make the energizing effect of $NaHCO_0$ stronger, since even small changes in pH can delay the point at which highly adapted individuals become fatigued (Krustrup et al., 2015b). Studies on less-trained groups, on the other hand (Zhou et al., 2022), might not fully understand how useful $NaHCO_1$ is because they may not have as much acidosis to begin with or may not put in as much effort during testing. (4) The current study focused on lactic acid and fatigue index, biomarkers directly linked to acidosis. In contrast, studies measuring broad performance metrics (e.g., time-to-exhaustion, technical skill) may overlook $NaHCO_3$'s mechanistic benefits. For example, Ragone et al. (2020) reported no improvement in jiu-jitsu performance but did not assess lactate kinetics, potentially missing subtle physiological effects.

Divergent findings in $NaHCO_3$ research underscore the importance of context-specific protocols. The good results of this study are probably due to three things: (1) testing that was specific to the sport, (2) the right dose to avoid GI problems, and (3) a group of highly trained people who had severe acidosis during intermittent exercise. Future research should prioritize sport-specific designs and standardized dosing regimens to clarify $NaHCO_3$'s role across disciplines.

Conclusions

Drinking sodium bicarbonate ($NaHCO_3$) before rigorous anaerobic exercise markedly decreases anaerobic fatigue and blood lactate concentrations. This effect arises from sodium bicarbonate's ability to maintain the body's pH by expediting the neutralization of lactic acid and H+ ions; therefore, it mitigates the impacts of metabolic acidosis during high-intensity exercise. These findings have considerable ramifications for dietary approaches designed to improve anaerobic endurance and expedite recovery in athletes engaged in high-intensity activities such as badminton, sprinting, or weightlifting. This research provides coaches with the opportunity to include sodium bicarbonate supplementation into training regimens by considering the ideal dosage (0.4 grams per kilogram of body weight) and timing of administration to mitigate adverse effects, including gastrointestinal disturbances. The sports nutrition sector may enhance product development by formulating supplements that are more efficacious and convenient, including readily soluble formulations or combinations with additional components that facilitate athlete recovery. Consequently, our results provide practical options for enhancing athlete performance and promote innovation in sports nutrition and health.

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References

Bishop, D., Edge, J., Thomas, C., & Mercier, J. (2007). High-intensity exercise acutely decreases the membrane content of MCT1 and MCT4 and buffer capacity in human skeletal muscle. *Journal of Applied Physiology*, *102*(2), 616–621. https://doi.org/10.1152/japplphysiol.00590.2006

Burke, L. M. (2013). Practical Considerations for Bicarbonate Loading and Sports Performance. *Nestle Nutrition Institute Workshop Series*, *75*, 15–26. https://doi.org/10.1159/000345814

Chycki, J., Kurylas, A., Maszczyk, A., Golas, A., & Zajac, A. (2018). Alkaline water improves exercise-induced metabolic acidosis and enhances anaerobic exercise performance in combat sport athletes. *PLoS ONE*, *13*(11), 1–10. https://doi.org/10.1371/journal.pone.0205708

Dalle, S., Koppo, K., & Hespel, P. (2021). Sodium bicarbonate improves sprint performance in endurance cycling. *Journal of Science and Medicine in Sport*, *24*(3), 301–306. https://doi.org/10.1016/j.jsams.2020.09.011

Driller, M. W., Gregory, J. R., Williams, A. D., & Fell, J. W. (2012). The Effects Of Serial And Acute NaHCO3 Loading in Well- Trained Cyclist. *Journal of Strenght and Conditioning Research*, *26*(10), 2791–2797.

Durkalec-Michalski, K., Zawieja, E. E., Podgórski, T., Zawieja, B. E., Michalowska, P., Łłoniewski, I., & Jeszka, J. (2018). The effect of a new sodium bicarbonate loading regimen on anaerobic capacity and wrestling performance. *Nutrients*, *10*(6), 1–16. https://doi.org/10.3390/nu10060697

Forbes, S. C., Candow, D. G., Smith-ryan, A. E., Hirsch, K. R., Roberts, M. D., Vandusseldorp, T. A., Stratton, M. T., Kaviani, M., & Little, J. P. (2020). Supplements and nutritional interventions to augment high-intensity interval training physiological and performance adaptations — A narrative review. *Nutrients*, *12*(2), 1–22. https://doi.org/10.3390/nu12020390

Grgic, J., Grgic, I., Del Coso, J., Schoenfeld, B. J., & Pedisic, Z. (2021). Effects of sodium bicarbonate supplementation on exercise performance: an umbrella review. *Journal of the International Society of Sports Nutrition*, *18*(1), 1–13. https://doi.org/10.1186/s12970-021-00469-7

Hadzic, M., Eckstein, M. L., & Schugardt, M. (2019). The Impact of Sodium Bicarbonate on Performance in Response to Exercise Duration in Athletes: A Systematic Review. *Journal of Sports Science & Medicine*, *18*(2), 271. /pmc/articles/PMC6544001/

Hartono, S., & Sukadiono. (2017). The effects of sodium bicarbonate and sodium citrate on blood pH, HCO3-, lactate metabolism and time to exhaustion. *Sport Mont*, *15*(1), 13–16.

Hecksteden, A., Heinze, T., Faude, O., Kindermann, W., & Meyer, T. (2015). Validity of Lactate Thresholds in Inline Speed Skating. *Journal of Strength and Conditioning Research*, *29*(9), 2497–2502. https://doi.org/10.1519/JSC.0b013e31828a485c

Hidayah, I. (2018). the Increased of Lactic Acid Concentration in the Blood After Work. *The Indonesian Journal of Occupational Safety and Health*, *7*(2), 131–141.

Hilton, N. P., Leach, N. K., Sparks, S. A., Gough, L. A., Craig, M. M., Deb, S. K., & McNaughton, L. R. (2019). A Novel Ingestion Strategy for Sodium Bicarbonate Supplementation in a Delayed-Release Form: a Randomised Crossover Study in Trained Males. *Sports Medicine - Open*, *5*(1). https://doi.org/10.1186/s40798-019-0177-0

Ito, S. (2019). High-intensity interval training for health benefits and care of cardiac diseases - The key to an efficient exercise protocol. *World Journal of Cardiology*, *11*(7), 171–188. https://doi.org/10.4330/wjc.v11.i7.171

Krustrup, P., Ermidis, G., & Mohr, M. (2015a). Sodium bicarbonate intake improves high-intensity intermittent exercise performance in trained young men. *Journal of the International Society of Sports Nutrition*, *12*(1). https://doi.org/10.1186/s12970-015-0087-6

Krustrup, P., Ermidis, G., & Mohr, M. (2015b). Sodium bicarbonate intake improves high-intensity intermittent exercise performance in trained young men. *Journal of the International Society of Sports Nutrition*, *12*(1), 1–7. https://doi.org/10.1186/s12970-015-0087-6

Kuntze, G., Mansfield, N., & Sellers, W. (2010). A biomechanical analysis of common lunge tasks in badminton. *Journal of Sports Sciences*, *28*(2), 183–191. https://doi.org/10.1080/02640410903428533

Lindh, A. M., Peyrebrune, M. C., Ingham, S. A., Bailey, D. M., & Folland, J. P. (2008). Sodium bicarbonate improves swimming performance. *International Journal of Sports Medicine*, *29*(6), 519–523. https://doi.org/10.1055/s-2007-989228

Manansang, G. R., Rumampuk, J. F., & Moningka, M. E. W. (2018). Perbandingan Tekanan Darah Sebelum dan Sesudah Olahraga Angkat Berat. *Jurnal E-Biomedik*, *6*(2). https://doi.org/10.35790/ebm.6.2.2018.21585

Mancha-Triguero, D., García-Rubio, J., Antúnez, A., & Ibáñez, S. J. (2020). Physical and Physiological Profiles of Aerobic and Anaerobic Capacities in Young Basketball Players. *International Journal of Environmental Research and Public Health*, *17*(4), 1409. https://doi.org/10.3390/ijerph17041409

Miller, P., Robinson, A. L., Sparks, S. A., Bridge, C. A., Bentley, D. J., & McNaughton, L. R. (2016). The Effects of Novel Ingestion of Sodium Bicarbonate on Repeated Sprint Ability. *Journal of Strength and Conditioning Research*, *30*(2), 561–568. https://doi.org/DOI: 10.1519/JSC.0000000000001126

Ooi, C. H., Tan, A., Ahmad, A., Kwong, K. W., Sompong, R., Ghazali, K. A. M., Liew, S. L., Chai, W. J., & Thompson, M. W. (2009). Physiological characteristics of elite and sub-elite badminton players. *Journal of Sports Sciences*, *27*(14), 1591–1599. https://doi.org/10.1080/02640410903352907

Patel, H., Alkhawam, H., Madanieh, R., Shah, N., Kosmas, C. E., & Vittorio, T. J. (2017). Aerobic vs anaerobic exercise training effects on the cardiovascular system . *World Journal of Cardiology*, *9*(2), 134. https://doi.org/10.4330/wjc.v9.i2.134

Phomsoupha, M., & Laffaye, G. (2015). The Science of Badminton: Game Characteristics, Anthropometry, Physiology, Visual Fitness and Biomechanics. *Sports Medicine*, *45*(4), 473–495. https://doi.org/10.1007/s40279-014-0287-2

Pruscino, C. L., Ross, M. L. R., Gregory, J. R., Savage, B., & Flanagan, T. R. (2008). Effects of sodium bicarbonate, caffeine, and their combination on repeated 200-m freestyle performance. *International Journal of Sport Nutrition and Exercise Metabolism*, *18*(2), 116–130. https://doi.org/10.1123/ijsnem.18.2.116

Ragone, L., Guilherme Vieira, J., Camaroti Laterza, M., Leitão, L., Da Silva Novaes, J., Macedo Vianna, J., & Ricardo Dias, M. (2020). Acute Effect of Sodium Bicarbonate Supplementation on Symptoms of Gastrointestinal Discomfort, Acid-Base Balance, and Performance of Jiu-Jitsu Athletes. *Journal of Human Kinetics*, *75*(1), 85–93. https://doi.org/10.2478/hukin-2020-0039

Rusdiawan, A., & Habibi, A. I. (2020). Efek pemberian jus semangka kuning terhadap tekanan darah, kadar asam laktat, dan daya tahan anaerobik setelah aktivitas anaerobic. *Jurnal SPORTIF : Jurnal Penelitian Pembelajaran*. https://doi.org/10.29407/JS_UNPGRI.VI.13712

Rusdiawan, A., Mar, A., & Prihatiningsih, S. (2020). The Changes in pH Levels , Blood Lactic Acid and Fatigue Index to Anaerobic Exercise on Athlete After. *Malaysian Journal of Medicine and Health Sciences*, *16*(10), 50–56.

Septiani, F. F., Ilyas, E. I., & Sadikin, M. (2010). Peran H + dalam Menimbulkan Kekelahan Otot : Pengaruhnya pada Sediaan Otot Rangka Rana Sp. *Majalah Kedokteran Indonesia*, *60*(4), 178–180. http://staff.ui.ac.id/system/files/users/ermita.isfandiary/publication/majalah_kedokteran_indonesia_vol_60_april_2010.pdf

Shalayel, M., & Ahmed, S. (2010). Lactic acid – the innocent culprit of muscle fatigue. *Sudan Journal of Medical Sciences*, *5*(2). https://doi.org/10.4314/sjms.v5i2.57816

Shelton, J., Kumar, G. V. P., Shelton, J., & Kumar, G. V. P. (2010). Sodium Bicarbonate—A Potent Ergogenic Aid? *Food and Nutrition Sciences*, *1*(1), 1–4. https://doi.org/10.4236/FNS.2010.11001

Shi, Y., Shi, H., Nieman, D. C., Hu, Q., Yang, L., Liu, T., Zhu, X., Wei, H., Wu, D., Li, F., Cui, Y., & Chen, P. (2019). Lactic acid accumulation during exhaustive exercise impairs release of neutrophil extracellular traps in mice. *Frontiers in Physiology*, *10*(JUN). https://doi.org/10.3389/fphys.2019.00709

Siegler, J. C., Marshall, P. W. M., Bishop, D., Shaw, G., & Green, S. (2016a). Mechanistic Insights into the Efficacy of Sodium Bicarbonate Supplementation to Improve Athletic Performance. *Sports Medicine - Open*, *2*(1), 1–13. https://doi.org/10.1186/s40798-016-0065-9

Siegler, J. C., Marshall, P. W. M., Bishop, D., Shaw, G., & Green, S. (2016b). Mechanistic Insights into the Efficacy of Sodium Bicarbonate Supplementation to Improve Athletic Performance. *Sports Medicine - Open 2016 2:1*, *2*(1), 1–13. https://doi.org/10.1186/S40798-016-0065-9

Sturgess, S., & Newton, R. U. (2008). Design and implementation of a specific strength program for badminton. *Strength and Conditioning Journal*, *30*(3), 33–41. https://doi.org/10.1519/SSC.0b013e3181771008

Theofilidis, G., Bogdanis, G., Koutedakis, Y., & Karatzaferi, C. (2018). Monitoring Exercise-Induced Muscle Fatigue and Adaptations: Making Sense of Popular or Emerging Indices and Biomarkers. *Sports*, *6*(4), 153. https://doi.org/10.3390/sports6040153

Wasserman, K. (1986). The anaerobic threshold: Definition, physiological significance and identification. *Advances in Cardiology*, *Vol. 35*(1), 1–23. https://doi.org/10.1159/000413434

Wee, E. H., Low, J. Y., Chan, K. Q., & Ler, H. Y. (2017). Effects of high intensity intermittent badminton multi-shuttle feeding training on aerobic and anaerobic capacity, leg strength qualities and agility. *IcSPORTS 2017 - Proceedings of the 5th International Congress on Sport Sciences Research and Technology Support*, *icSPORTS*, 39–47. https://doi.org/10.5220/0006501000390047

Westerblad, H., Allen, D. G., & Lännergren, J. (2002). Muscle fatigue: Lactic acid or inorganic phosphate the major cause? *News in Physiological Sciences*, *17*(1), 17–21. https://doi.org/10.1152/physiologyonline.2002.17.1.17

Wiriawan, O., Rusdiawan, A., Kusuma, D. A., Firmansyah, A., García-Jiménez, J. V., Zein, M. I., Pavlovic, R., Nowak, A. M., Susanto, N., & Pranoto, A. (2024). Unilateral Hamstring Muscle Strengthening Exercises Can Improve Hamstring Asymmetry and Increase Jumping Performance in Sub-Elite Badminton Athletes. *Retos*, *54*, 761–770. https://doi.org/10.47197/retos.v54.103783

Zhou, N., Fan, Y., Kong, X., Wang, X., Wang, J., & Wu, H. (2022). Effects of serial and acute enteric-coated sodium bicarbonate supplementation on anaerobic performance, physiological profile, and metabolomics in healthy young men. *Frontiers in Nutrition*, *9*. https://doi.org/10.3389/fnut.2022.931671

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