

Effects of Combined Versus Isolated Beta-Alanine and Sodium Bicarbonate Supplementation on Physical Capacity in Highly Trained Female Basketball Players: A Randomized Controlled Trial

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Purpose: To examine the effects of combined versus isolated beta-alanine (BA) and sodium bicarbonate (SB) supplementation on physical capacity in highly trained female basketball players. **Methods:** Sixty-eight athletes aged 21.4 (4.2) years participated in a randomized, double-blind, placebo (PL)-controlled parallel trial. Participants were assigned to one of four treatments: BA+SB, BA+PL_{SB}, PL_{BA}+SB, or PL_{BA}+PL_{SB}. They received BA or PL_{BA} (6.4 g·d⁻¹) for 28 days. In the final 7 days, SB or PL_{SB} (0.3 g·kg⁻¹·d⁻¹) was added to the ongoing supplementation. Exercise tests included countermovement jump (CMJ), Wingate Anaerobic Test (WAnT), and incremental cycling test. The tests were performed in the following order: CMJ₁, WAnT₁, incremental cycling test, WAnT₂, and CMJ₂. Heart rate, ratings of perceived exertion, body mass, and composition were also assessed. Data were analyzed with repeated-measures analysis of variance. **Results:** BA+SB and PL_{BA}+SB supplementation increased peak power during WAnT₁ compared to presupplementation (both $P < .001$; *large* effect). Additionally, mean heart rate was lower in BA+SB during incremental cycling test at postsupplementation compared to PL_{BA}+SB ($P = .04$; *large* effect). BA+PL_{SB} did not influence any physical capacity outcomes. Moreover, no changes in ratings of perceived exertion, body mass, and composition were observed. **Conclusions:** BA+SB and PL_{BA}+SB supplementation enhanced peak power in WAnT₁ without compromising subsequent physical capacity indices. BA+SB potentially reduced cardiovascular strain during submaximal exercise. In contrast, BA+PL_{SB} did not confer any ergogenic benefits. These findings suggest that SB-containing protocols may improve high-intensity capabilities in highly trained female basketball players.

Keywords: anaerobic performance, athletes, buffering agents, ergogenic aids, sports nutrition

Beta-alanine (BA) and sodium bicarbonate (SB) are 2 widely studied buffering agents used to enhance exercise capacity, particularly during efforts in which muscle acidosis is a limiting factor.^{1,2} BA increases intramuscular carnosine, an effective intracellular buffer, that delays muscular fatigue by attenuating H⁺ accumulation.¹ In contrast, SB increases extracellular buffering capacity, enhancing the efflux of H⁺ from muscle cells into the blood, thereby attenuating decreases in pH during intense exercise.² The effects of these ergogenic aids are well established across high-intensity activities.^{1,2}

Their distinct but complementary buffering mechanisms have prompted research into combined use and findings reported in a systematic review suggested additional performance effects of co-ingestion.³ Despite the growing body of evidence, most previous studies have focused on individual or endurance-based sports, with relatively few addressing team sport athletes.³ Among these, basketball has been insufficiently studied, limiting the direct applicability of findings to this population. Addressing this gap is particularly important because basketball presents a distinct combination of physiological and performance demands that are not fully captured by studies on other sports. Specifically, this sport is characterized by repeated bouts of short-duration sprints, jumps, and rapid changes of direction, all interspersed with brief recovery periods.⁴ The capacity to maintain performance during such repeated high-intensity efforts is critical for match outcomes. Thus, enhancing buffering capacity through supplementation could improve the performance of basketball players. Furthermore, a crucial consideration is the limited focus on female athletes in existing sports science research.⁵ There is a need for studies that directly inform evidence-based practice in this population. Consequently, investigating the ergogenic effects of BA and SB supplementation in female basketball athletes is therefore fundamental to provide guidance that can enhance their training outcomes and competitive performance. Thus, this study aimed to examine combined versus isolated BA and SB supplementation on physical capacity in highly trained female basketball players. Within this context, the primary outcomes of the study were to determine changes in: (1) countermovement jump (CMJ), (2) Wingate

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Anaerobic Test (WAnT), and (3) incremental cycling test (ICT). Secondary outcomes included: (1) body mass (BM) and composition, (2) heart rate (HR), and (3) ratings of perceived exertion (RPE). Based on available data, we hypothesized that combined BA+SB supplementation would elicit greater improvements in CMJ, WAnT, and ICT performance compared to each individual supplement alone (BA or SB) or placebo (PL). We further expected that BA and SB administered separately would each improve physical capacity compared to PL. Additionally, we hypothesized that all supplementation strategies would maintain RPE, BM, as well as HR.

Methods

Participants

Sixty-eight female basketball players completed the study (aged 21.4 [4.2] y; training time: 10.5 [0.9] h·wk⁻¹; competition frequency: 1.2 [0.4] matches·wk⁻¹; basketball experience 11.3 [4.8] y). Participants were classified as highly trained (n=36) or elite (n=32) athletes.⁶ Eligibility criteria: female sex, age 16–35 years (inclusive), ≥4 years of basketball training, ≥4 training sessions·h·wk⁻¹, medical clearance for competitive sports, good health, and written consent. Exclusion: recent injury, health contraindications, and use of ergogenic or buffering supplements (except continuous protein, carbohydrate, or isotonic beverages) within 3

months before enrollment. The study was approved by the Bioethics Committee at Poznan University of Medical Sciences (No. 352/24) and registered at ClinicalTrials.gov (NCT07092930). It was conducted according to the Declaration of Helsinki⁷ and reported following the CONSORT guidelines.⁸ The corresponding checklist is summarized in [Supplementary Table S1](#) (available online).

Study Design and Visits

This randomized, double-blind, PL-controlled parallel study included 2 *Phases* of supplementation and 3 visits (T₀–T₂; Figure 1). The first visit (T₀) familiarized participants with all procedures. Following presupplementation visit (T₁), athletes were randomized by an independent biostatistician using a stratified design based on CMJ₁ and BM results to one of four treatments: BA+SB, BA+PL_{SB}, PL_{BA}+SB, or PL_{BA}+PL_{SB}. Randomization codes were concealed from participants and researchers until data analysis. To standardize conditions, athletes avoided high-intensity or long-duration training for ≥24 hour before testing. Measurements were conducted at their usual training times. For 2 days prior to each visit, each participant followed the same individualized diet. Additionally, they consumed a standardized meal 3 hours before testing,⁹ with adherence verified upon arrival. At each visit, hydration status was assessed via urine sample¹⁰ (PAL-10S, ATAGO). The flow diagram of the 2-Phase study design is summarized in Figure 1.

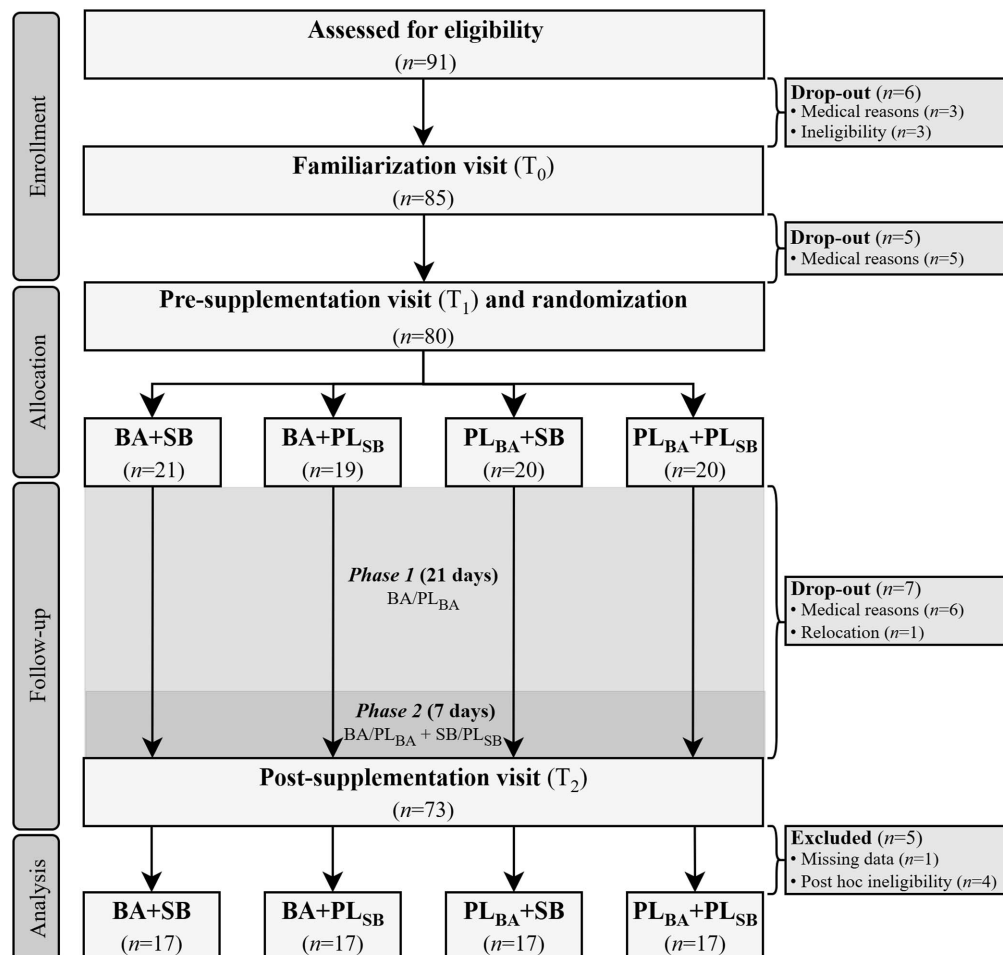


Figure 1 — Flow diagram of the 2-Phase study design. BA indicates beta-alanine; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate.

Supplementation Protocol

In *Phase 1*, participants ingested $6.4 \text{ g} \cdot \text{d}^{-1}$ of BA (Beta-Alanine, OstroVit) for 21 days, divided into 4 equal doses of 1.6 g each, consumed with main meals (breakfast, lunch, and dinner) and 1 snack.¹ In *Phase 2*, BA supplementation was continued for an additional 7 days, adding $0.3 \text{ g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$ of SB (Alkala N, Sanum-Kehlbeck), divided into 3 equal doses taken with main meals.² PLs were pure starch for BA (PL_{BA}) and a mixture for SB (PL_{SB}) containing an equimolar amount of sodium as SB sodium (275 mg NaCl per 1 g), with the remainder being starch. All supplements and PLs were in opaque capsules. Weekly contact was maintained to support participant motivation. Compliance was verified through online logs and collection of capsule containers after the protocol. The procedures and assessment timeline are summarized in Figure 2.

Anthropometric and Body Composition

Anthropometric and body composition (Figure 2) were evaluated at each visit's start. BM and height were measured in duplicate using a calibrated scale with stadiometer (WPT 60/150 OW, Radwag). Body composition was assessed via bioelectrical impedance analysis (101 BIVA PRO, Akern), according to established guidelines.^{11,12} The outcome measures were total body water, fat-free mass, and fat mass.

Countermovement Jump

Participants performed 2 CMJ series (CMJ₁ and CMJ₂; Figure 2) on the platform (OptoJump Next, Microgate), following procedures.¹³ Each series included 3 jumps with 30 seconds of passive rest. A standardized 15-minute warm-up preceded CMJ₁ (Warm-up; Figure 2). The results included mean and peak for both jump height (CMJ_{MEAN_JH}; CMJ_{PEAK_JH}) and power (CMJ_{MEAN_P}; CMJ_{PEAK_P}). Power was calculated using the Sayers equation.¹⁴

Wingate Anaerobic Test

Participants performed 2 WAnT series (WAnT₁ and WAnT₂; Figure 2) on a cycle ergometer (Monark 894E, Monark), following the procedures,¹⁵ previously implemented by our team.¹⁶ Each 30-second test based on recommended workload of 7.5% BM. Verbal encouragement was provided to maintain maximal effort. The analyzed variables were peak power (WAnT_{PEAK_P}), mean power (WAnT_{MEAN_P}), minimum power (WAnT_{MIN_P}), and time to peak power (WAnT_{TTPeak_P}).

Incremental Cycling Test

Participants performed an ICT (Figure 2) to volitional exhaustion on a cycle ergometer (Ergoline E100P-K, Cosmed), using the adapted protocol.¹⁷ The test started at 75 W, increasing by 25 W every 90 seconds at cadence approximately 70 revolutions per minute. It ended if cadence dropped below 60 revolutions per minute for 5 seconds or upon exhaustion. Verbal encouragement was provided throughout the test. Time to exhaustion (ICT_{TTE}) was measured.

Heart Rate Monitoring

HR was continuously monitored during procedures using an HR monitor (HRM-Dual, Garmin). Maximum HR (HR_{MAX}) was recorded during WAnTs and ICT, while mean HR (HR_{MEAN}) was additionally measured during ICT.

Ratings of Perceived Exertion

RPE (RPE₁₋₄; Figure 2) were measured using the 6 to 20 Borg scale.¹⁸ RPE₁ was assessed before CMJ₁, while RPE₂₋₄ were recorded immediately after each exercise bout.

Sample Size Calculation

Sample size was calculated a priori using *F* tests for repeated-measures analysis of variance within-between interaction (G*Power, version 3.1.9.7, Heinrich Heine University Düsseldorf).¹⁹ Parameters included: power 80%,²⁰ effect size 0.43,²¹ 4 treatments, 2 visits, nonsphericity correction of one, and SPSS-style options. Results indicated a minimum of 68 participants (17 per treatment) for adequate power. Based on our prior data showing approximately 35% dropout among highly trained athletes,²² the targeted initial enrollment was adjusted accordingly.

Statistical Analysis

Statistical analyses evaluated *treatment*, *time*, and their interaction (*treatment* × *time*) effects (Statistica 13.3, TIBCO Software Inc). Normality (Shapiro-Wilk test) and homogeneity of variances (Levene's test) were assessed prior to analysis. Despite minor violations, RM ANOVA is considered robust under conditions of equal treatment group sizes.²³⁻²⁵ Significant effects of *treatment* and *treatment* × *time* interaction were followed by Tukey's HSD post hoc test. Statistical significance was set at *P* < .05. Descriptive data

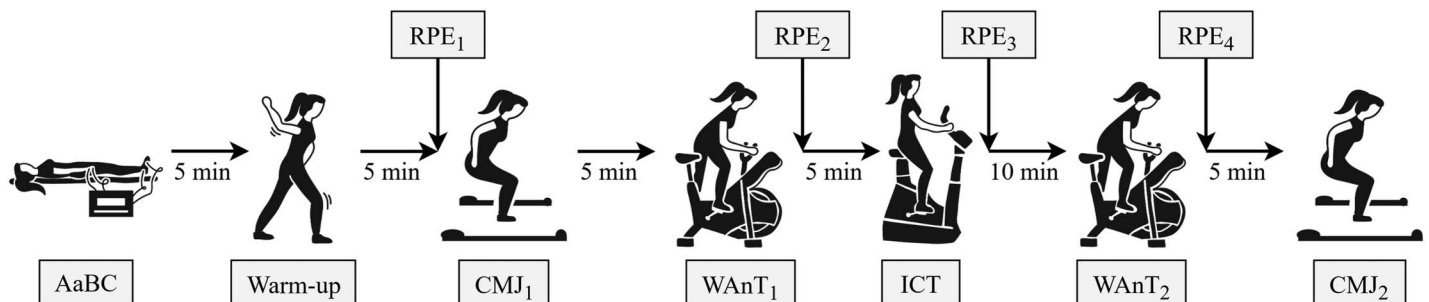


Figure 2 — An overview of the procedures and assessment timeline for each visit. AaBC indicates anthropometric and body composition; CMJ, countermovement jump; ICT, incremental cycling test; RPE, ratings of perceived exertion; WAnT, Wingate Anaerobic Test.

are presented as mean (SD), with 95% CIs for significant *treatment* and *treatment* $\times$ *time* interaction effects. Partial eta square (η^2) values were interpreted based on conventional benchmarks: *small* ($\geq .01$), *medium* ($\geq .06$), and *large* ($\geq .14$) effects.²⁶

Results

Anthropometric and Body Composition

No effects of *treatment*, *time* or *treatment* $\times$ *time* interaction on BM, total body water, fat-free mass, and fat mass were observed. The results are summarized in [Supplementary Table S2](#) (available online).

Countermovement Jump₁

A significant effect of *time* on CMJ_{MEAN_JH} ($F_{1,64} = 13.407$, $\eta^2 = .17$; *large* effect), CMJ_{PEAK_JH} ($F_{1,64} = 17.477$, $\eta^2 = .21$; *large* effect), CMJ_{MEAN_P} ($F_{1,64} = 10.876$, $\eta^2 = .15$; *large* effect), and CMJ_{PEAK_P} ($F_{1,64} = 14.711$, $\eta^2 = .19$; *large* effect) was observed. No effects of *treatment* or *treatment* $\times$ *time* interaction on CMJ_{MEAN_JH}, CMJ_{PEAK_JH}, CMJ_{MEAN_P}, nor CMJ_{PEAK_P} were found. The results are summarized in Table 1.

Wingate Anaerobic Test₁

A significant *treatment* $\times$ *time* interaction on WAnT_{PEAK_P} ($F_{3,64} = 4.732$, $\eta^2 = .18$; *large* effect) was observed. Post hoc analysis indicated a significant difference at T₂ versus T₁ in BA+SB (95% CI, 748–895 W vs 95% CI, 696–827 W; $P < .001$) and PL_{BA}+SB (95% CI, 766–918 W vs 95% CI, 701–865 W; $P < .001$). A significant effect of *time* on WAnT_{PEAK_P} ($F_{1,64} = 34.655$, $\eta^2 = .35$; *large* effect) was also found, with no effect of *treatment*. A significant effect of *time* on WAnT_{TPEAK_P} ($F_{1,64} = 9.693$, $\eta^2 = .13$; *medium* effect) was observed, with no effects of *treatment* or *treatment* $\times$ *time* interaction. No effects of *treatment*, *time*, or *treatment* $\times$ *time* interaction were observed on WAnT_{MEAN_P} nor WAnT_{MIN_P}. The results are summarized in Table 2 and Figure 3.

Incremental Cycling Test

No effects of *treatment*, *time*, or *treatment* $\times$ *time* interaction were observed on ICT_{TTE}. The results are summarized in Figure 4A.

Wingate Anaerobic Test₂

A significant effect of *time* on WAnT_{PEAK_P} ($F_{1,64} = 25.530$, $\eta^2 = .29$; *large* effect), WAnT_{MEAN_P} ($F_{1,64} = 13.713$, $\eta^2 = .18$; *large*

Table 1 Mean, Peak Jump Height, and Power in Countermovement Jump₁

Variable	Unit	Visit	Treatment				P		
			BA+SB	BA+PL _{SB}	PL _{BA} +SB	PL _{BA} +PL _{SB}	Treatment	Time	Treatment $\times$ time
Mean jump height	cm	T ₁	30.8 (4.3)	30.3 (3.6)	30.8 (4.9)	30.2 (4.5)	.921	.001	.873
		T ₂	31.7 (4.9)	30.8 (3.2)	31.4 (4.9)	30.7 (4.2)			
Peak jump height	cm	T ₁	31.8 (4.2)	30.9 (3.6)	31.6 (4.8)	31.0 (4.5)	.914	.002	.931
		T ₂	32.8 (5.2)	31.9 (3.5)	32.2 (4.9)	31.9 (4.1)			
Mean power	W	T ₁	2990 (366)	3035 (647)	3032 (495)	2990 (468)	.996	.003	.286
		T ₂	3068 (365)	3062 (629)	3048 (443)	3023 (485)			
Peak power	W	T ₁	3049 (368)	3073 (646)	3078 (511)	3039 (485)	.998	.003	.447
		T ₂	3134 (375)	3127 (636)	3098 (438)	3095 (493)			

Abbreviations: BA, beta-alanine; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit. Note: Data are shown as mean (SD).

Table 2 Peak, Mean and Minimum Power, Time to Peak Power, and Maximum HR in Wingate Anaerobic Test₁

Variable	Unit	Visit	Treatment				P		
			BA+SB	BA+PL _{SB}	PL _{BA} +SB	PL _{BA} +PL _{SB}	Treatment	Time	Treatment $\times$ time
Peak power	W	T ₁	761 (127)	823 (203)	783 (160)	817 (139)	.897	.001	.005
		T ₂	821 (143)*	828 (198)	842 (149)*	841 (139)			
Mean power	W	T ₁	505 (59)	524 (114)	516 (97)	518 (64)	.982	.315	.073
		T ₂	516 (55)	520 (109)	519 (89)	517 (70)			
Minimum power	W	T ₁	322 (32)	340 (76)	327 (61)	313 (53)	.816	.614	.205
		T ₂	328 (34)	329 (79)	318 (63)	321 (48)			
Time to peak power	s	T ₁	2.6 (0.7)	2.1 (0.9)	2.5 (1.0)	2.3 (1.1)	.913	.003	.429
		T ₂	1.9 (1.1)	2.1 (0.6)	1.9 (0.8)	1.8 (0.5)			
Maximum HR	bpm	T ₁	174 (12)	174 (10)	178 (9)	178 (10)	.235	.097	.768
		T ₂	172 (12)	173 (9)	178 (9)	178 (10)			

Abbreviations: BA, beta-alanine; bpm, beats per minute; HR, heart rate; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit. Note: Data are shown as mean (SD).

*Significant difference compared to T₁ within the same treatment ($P < .05$).

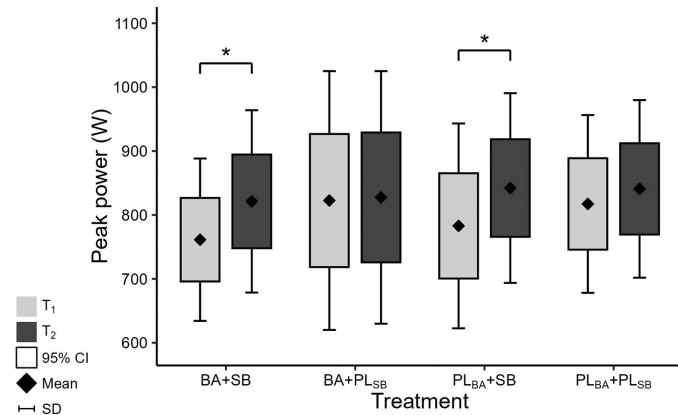


Figure 3 — Peak power in Wingate Anaerobic Test₁. *Significant difference ($P < .05$). BA indicates beta-alanine; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit.

effect), and WAnT_{TTPEAK_P} ($F_{1,64} = 10.777$, $\eta^2 = .14$; large effect) was observed. No effects of *treatment* or *treatment* $\times$ *time* interaction on WAnT_{PEAK_P}, WAnT_{MEAN_P}, nor WAnT_{TTPEAK_P} were found. No effects of *treatment*, *time*, or *treatment* $\times$ *time* interaction were observed on WAnT_{MIN_P}. The results are summarized in Table 3.

Countermovement Jump₂

A significant effect of *time* on CMJ_{MEAN_JH} ($F_{1,64} = 29.427$, $\eta^2 = .31$; large effect), CMJ_{PEAK_JH} ($F_{1,64} = 22.442$, $\eta^2 = .26$; large effect), CMJ_{MEAN_P} ($F_{1,64} = 33.286$, $\eta^2 = .34$; large effect), and CMJ_{PEAK_P} ($F_{1,64} = 25.860$, $\eta^2 = .29$; large effect) was observed. No effects of *treatment* or *treatment* $\times$ *time* interaction on CMJ_{MEAN_JH}, CMJ_{PEAK_JH}, CMJ_{MEAN_P}, nor CMJ_{PEAK_P} were found. The results are summarized in Table 4.

Heart Rate Monitoring

A significant effect of *time* on HR_{MAX} during WAnT₁ ($F_{1,64} = 2.83$, $\eta^2 = .02$; small effect) was observed, with no effects of *treatment* or *treatment* $\times$ *time* interaction. A significant effect of *treatment* on HR_{MEAN} during ICT ($F_{3,64} = 3.46$, $\eta^2 = .14$; large effect) was observed. Post hoc analysis indicated a significant difference at T₂ in BA+SB versus PL_{BA}+SB (95% CI, 147–159 bpm vs 95% CI, 158–167 bpm; $P = .04$). A significant effect of *time* on HR_{MEAN} during ICT ($F_{1,64} = 8.10$, $\eta^2 = .11$; medium effect) was also found, with no effect of *treatment* $\times$ *time* interaction. A significant effect of *time* on HR_{MAX} during ICT ($F_{1,64} = 6.45$, $\eta^2 = .09$; medium effect) was observed, with no effects of *treatment* or *treatment* $\times$ *time* interaction. A significant effect of *time* on HR_{MAX} during WAnT₂ ($F_{1,64} = 4.94$, $\eta^2 = .07$; medium effect) was observed, with no effects of *treatment* or *treatment* $\times$ *time* interaction. The results are summarized in Table 2 and 3, Figure 4B and 4C.

Ratings of Perceived Exertion

A significant effect of *time* on RPE₂ ($F_{1,64} = 4.255$, $\eta^2 = .06$; medium effect) was observed, with no effects of *treatment* or *treatment* $\times$ *time* interaction. No effects of *treatment*, *time*, or *treatment* $\times$ *time* interaction on RPE₁, RPE₃, nor RPE₄ were found. The results are summarized in Supplementary Table S3 (available online).

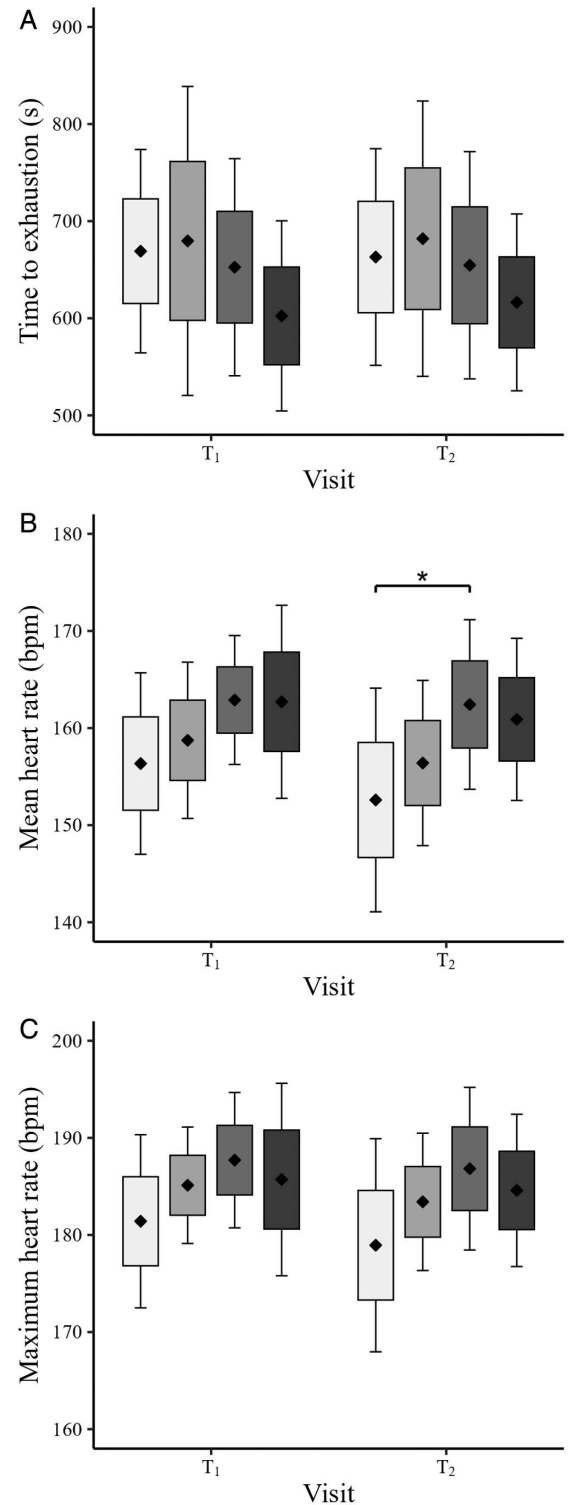


Figure 4 — Time to exhaustion (A), mean (B) and (C) maximum HR in ICT. *Significant difference ($P < .05$). BA indicates beta-alanine; HR, heart rate; ICT, incremental cycling test; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit.

Discussion

To the best of our knowledge, this is the first randomized controlled study to investigate the effects of combined versus isolated BA and

Table 3 Peak, Mean and Minimum Power, Time to Peak Power, and Maximum HR in Wingate Anaerobic Test₂

Variable	Unit	Visit	Treatment				P		
			BA+SB	BA+PL _{SB}	PL _{BA} SB	PL _{BA} +PL _{SB}	Treatment	Time	Treatment × time
Peak power	W	T ₁	713 (132)	760 (177)	715 (145)	738 (111)	.904	.001	.183
		T ₂	752 (134)	771 (160)	770 (150)	775 (127)			
Mean power	W	T ₁	483 (62)	492 (103)	487 (90)	485 (64)	.994	.002	.691
		T ₂	491 (53)	497 (102)	496 (91)	498(68)			
Minimum power	W	T ₁	308 (35)	313 (65)	284 (81)	293 (81)	.790	.196	.387
		T ₂	310 (41)	313 (80)	311 (69)	298 (51)			
Time to peak power	s	T ₁	2.8 (1.6)	2.5 (1.0)	2.5 (1.3)	2.1 (0.7)	.270	.002	.638
		T ₂	2.1 (0.9)	1.9 (0.7)	2.3 (0.9)	1.8 (0.7)			
Maximum HR	bpm	T ₁	177 (10)	179 (5)	181 (8)	181 (8)	.201	.030	.487
		T ₂	175 (10)	178 (5)	181 (7)	180 (9)			

Abbreviations: BA, beta-alanine; bpm, beats per minute; HR, heart rate; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit. Note: Data are shown as mean (SD).

Table 4 Mean, Peak Jump Height, and Power in CMJ₂

Variable	Unit	Visit	Treatment				P		
			BA+SB	BA+PL _{SB}	PL _{BA} +SB	PL _{BA} +PL _{SB}	Treatment	Time	Treatment × time
Mean jump height	cm	T ₁	26.8 (5.0)	26.5 (3.0)	26.3 (3.6)	25.4 (3.9)	.546	.001	.454
		T ₂	28.4 (5.8)	27.8 (3.2)	27.7 (4.6)	26.0 (2.9)			
Peak jump height	cm	T ₁	27.7 (5.3)	27.6 (3.1)	27.0 (3.7)	26.4 (3.8)	.518	.001	.182
		T ₂	29.5 (6.1)	28.9 (3.6)	28.4 (4.6)	26.7 (2.8)			
Mean power	W	T ₁	1909 (409)	1905 (328)	1903 (305)	1822 (352)	.721	.001	.356
		T ₂	2039 (465)	1996 (325)	2003 (353)	1971 (316)			
Peak power	W	T ₁	2723 (420)	2746 (624)	2725 (548)	2809 (528)	.940	.001	.916
		T ₂	2825 (381)	2812 (594)	2809 (528)	2725 (436)			

Abbreviations: BA, beta-alanine; PL_{BA}, placebo (as BA); PL_{SB}, placebo (as SB); SB, sodium bicarbonate; T₁, presupplementation visit; T₂, postsupplementation visit. Note: Data are shown as mean (SD).

SB supplementation in highly trained female basketball players, a limited population in sports nutrition research.⁵ The present study provides novel evidence that protocols containing SB, with or without BA, were associated with improved WAnT_{PEAK_P} in first bout within treatments (T₂ vs T₁). Furthermore, analysis indicated that the combination of BA+SB may also reduce cardiovascular strain, as reflected by significantly lower HR_{MEAN} during ICT compared to PL_{BA}+SB at T₂. These findings may support evidence-based supplementation strategies to enhance anaerobic performance in female basketball players.

Effects on Wingate Anaerobic Tests

Results showed that WAnT_{PEAK_P} in first bout was improved at T₂ compared to T₁ in both BA+SB and PL_{BA}+SB (Figure 3), supporting SB's ergogenic effect by enhancing extracellular buffering and facilitating proton efflux.² Although the *treatment* × *time* interaction on WAnT_{MEAN_P} in first bout was not statistically significant ($P = .073$), the result may point to potential practical benefits for overall anaerobic work capacity that may hold practical relevance and warrants further investigation (Table 2). Interestingly, BA+PL_{SB} did not influence WAnT₁, aligning with evidence indicating its greater efficacy in sustained high-intensity efforts (1–4 min) rather

than brief maximal tasks.¹ In WAnT₂, no *treatment* or *treatment* × *time* interaction effects emerged. This lack of difference, however, may reflect the influence of testing protocol. The 10-minute passive recovery between ICT and WAnT₂ could have allowed sufficient recovery in these highly trained female athletes, potentially masking supplementation effects in the second bout of WAnT. A comparable protocol previously conducted in elite female wrestlers from our laboratory²² involved similar testing structure: WAnT₁ followed by 5-minute rest, a high-intensity dummy throw test, and subsequent 10 minutes of rest prior to WAnT₂. Despite no changes in peak power or mean power in WAnTs after SB supplementation in that study, subtle improvements in mid-bout performance suggests that buffering benefits may emerge under fatigue. Notably, the intermediate test used in that protocol was more anaerobically demanding than the ICT implemented in the present study, which may partially explain the greater sensitivity of fatigue-related effects observed. These methodological considerations underscore the importance of protocol design in detecting supplementation effects. Importantly, the maintenance of performance despite higher WAnT_{PEAK_P} in first bout suggests that SB allows greater maximum efforts without decrements in subsequent bouts. Similar findings were reported in trained swimmers, where chronic BA (3.2 g·d⁻¹ for 1 wk and 6.4 g·d⁻¹ for 3 wk) combined with acute SB (0.3 g·kg⁻¹) ingestion, as well as SB alone, improved 200-m

performance.²⁷ After 30-minute rest, 100-m performance improved mainly with SB, while BA alone had minimal effects. Although swimming differs biomechanically from cycling-based WAnT protocol, these results reinforce SB's ergogenic benefits across diverse high-intensity exercise, whereas BA's efficacy may be more task-specific. Additionally, in judo and jiu-jitsu competitors performing 4 repeated 30-second upper-body Wingate tests, BA and SB alone increased total work done by ~7% and 8%, respectively, with BA+SB co-ingestion resulting in an additive ~14% improvement compared to separated BA or SB ingestion.²⁸ For mean power output, BA+SB enhanced all bouts; BA alone improved the second and third (trend in fourth) and SB alone improved the fourth (trends in second and third) bout. Notably, BA supplementation was similar to the present protocol (6.4 g·d⁻¹ for 4 wk) and SB was also administered chronically for 7 days, but at a higher dose (0.5 g·kg⁻¹·d⁻¹). Conversely, in recreationally active male games, players performing 5 repeated 6-second sprints under hypoxia at baseline and after each half of a football-specific intermittent treadmill protocol, neither BA alone (6.4 g·d⁻¹ for 5 wk) nor BA+SB (acute SB at 0.3 g·kg⁻¹) improved mean or peak power output, with only a trivial trend for SB.²⁹ Thus, buffering supplementation seems to offer limited benefits for very brief sprints, especially under hypoxic stress. These findings are practically relevant in basketball, where repeated maximal anaerobic actions, such as sprints, rebounds, and explosive defensive efforts, require both high peak power and the stability to maintain performance across bouts.⁴ Collectively, they highlight that SB, alone or with BA, enhances peak power in repeated high-intensity efforts, whereas BA's effects remain task and duration specific. This reinforces the potential utility of SB and BA+SB for enhancing repeated anaerobic performance in basketball competition settings.

Effects on Incremental Cycling Test

In the present study, supplementation did not affect ICT_{TTE}. However, HR_{MEAN} was lowered at T_2 in BA+SB compared to PL_{BA+SB} (Figure 4B). This reduction may indicate improved cardiovascular or metabolic efficiency during submaximal aerobic efforts, possibly attributable to complementary intracellular (BA) and extracellular (SB) buffering mechanisms. Previous research reported significant increases in TTE following BA (6.4 g·d⁻¹ for 4 wk) combined with acute SB supplementation (0.3 g·kg⁻¹) in recreationally active males performing test at 110% maximal power output.³⁰ Improvements of +12.1% and +16.2% compared to baseline were observed in BA alone and BA+SB, respectively, while the additional increase in BA+SB over BA alone was not observed. Differences in total work done mirrored those of TTE. However, these findings are based on a single continuous high-intensity protocol, whereas our study employed an incremental ramp test to volitional exhaustion. These methodological differences, including exercise modality, intensity, and protocol design, may explain the divergent results. Similarly, highly trained male cyclists undergoing BA (65 mg·kg⁻¹·d⁻¹ for 4 wk) combined with acute SB supplementation (0.3 g·kg⁻¹) improved mean power and total work during a 4 minute cycling time trial, while BA alone did not improve performance.³¹ This highlights SB's dominant role in enhancing severe-intensity continuous exercise in this population. Another study involving recreationally active males used a 6-week BA supplementation protocol (4.8 g·d⁻¹ for 4 wk, then 6.4 g·d⁻¹ for 2 wk) combined with acute SB dosing (0.3 g·kg⁻¹) in a cross-over design.³² While TTE was improved in both BA alone and BA+SB compared to PL (+14% and +16%, respectively), no differences in

repeated sprint ability were observed. Overall, these findings suggest that while BA supplementation may improve performance in continuous high-intensity endurance tasks, whereas SB alone or with BA appears more effective in enhancing severe-intensity continuous exercise performance. Collectively, this indicates that combined intra- and extracellular buffering supplementation may reduce cardiovascular strain during submaximal efforts. This could translate to more efficient submaximal recovery phases during basketball play.⁴

Effects on Countermovement Jumps

No *treatment* or *treatment* × *time* interaction effects were observed on any CMJ₁ and CMJ₂ variables, while improvements over time likely reflected neuromuscular adaptation, familiarization or potentiation effects rather than supplementation *per se*. The outcomes align with the current evidence that BA or SB supplementation predominantly enhance high-intensity capacity.^{1,2} Interestingly, despite higher WAnT_{PEAK_P} outputs observed in first bout among SB treatments, CMJ₂ performance was not impaired, suggesting that SB supplementation enabled greater preceding anaerobic effort without compromising subsequent neuromuscular performance. These findings may hold practical relevance for basketball players, where repeated high-intensity tasks are interspersed with explosive movements such as jumps.⁴ Collectively, these results indicate that BA and SB may not directly enhance jump performance. However, SB's buffering effects may support preceding high-intensity efforts without impairing subsequent neuromuscular outputs.

Effects on Anthropometric and Body Composition

No changes in BM, total body water, fat-free mass, and fat mass were observed across visits. The stability of these measures also supports the internal validity of performance findings, as the outcomes were not confounded by BM and composition fluctuations. Additionally, this indicates that supplementation does not induce unwanted fluid shifts or mass changes, supports its practical integration into athlete training and nutrition plans.

Effects on Ratings of Perceived Exertion

No *treatment* or *treatment* × *time* interaction effects were observed on RPE, aligning with previous research indicating that neither BA, SB, nor their combination affected RPE.²⁸ Notably, this stability in RPE was maintained despite an increase in WAnT_{PEAK_P} in first bout in the SB-containing treatments, suggesting that buffering supplementation allowed athletes to perform at higher intensities without a corresponding rise in perceived effort. This supports the practical applicability of such strategies for sustaining high-intensity performance without added subjective fatigue.

Study Limitations

A potential limitation of our study is the fact that testing did not occur during the same menstrual cycle phase for all participants. Nevertheless, this was mitigated by verifying individual cycle phases at each visit using menstrual tracking applications and urinary luteinizing hormone testing.³³ Importantly, none of the athletes reported menstrual phase-related symptoms or subjective discomfort at the time of testing that could have plausibly influenced performance outcomes.³⁴ Moreover, recent comprehensive

evidence suggests that short-term fluctuations in reproductive hormones are unlikely to meaningfully affect exercise capacity.³⁵ Practical constraints also limit the feasibility of menstrual cycle-based scheduling in elite team sports. Our 4-week supplementation protocol coincided with ongoing league and cup matches scheduled independently of athlete or coaching input. As a result, both performance testing and competitive play occurred irrespective of menstrual cycle phase, aligning with the real-world context of the studied population. A further limitation may be the lack of direct in-game performance evaluation. Nonetheless, the implemented laboratory-based protocols provided standardization and high relevance for basketball-specific demands.³⁶ Another potential methodological limitation relates to the 10-minute passive recovery between ICT and WAnT₂. While this rest duration was based on our previous protocols²² and ensured standardization across participants, it may have allowed sufficient recovery to attenuate fatigue-induced (after WAnT₁ and ICT) performance declines. As a result, this could have reduced the sensitivity of WAnT₂ to detect treatment-related buffering effects. In addition to test sequencing, the choice of supplementation form may also represent a methodological consideration. Although the rapid-release BA formulation used in our study reflects common practice in applied sports settings, emerging evidence suggests that sustained-release formulations may offer slightly more effectively carnosine loading while reducing paresthesia.³⁷ Future studies comparing release kinetics in elite athletic populations are warranted to clarify potential practical advantages.

Practical Applications

The findings suggest that chronic BA (6.4 g·d⁻¹ for 28 d) combined with short-term SB (0.3 g·kg⁻¹·d⁻¹ for 7 d) supplementation may enhance peak power during repeated high-intensity actions typical of basketball.⁴ Moreover, BA+SB may reduce cardiovascular strain during submaximal exercise, which could enhance recovery between bouts. These results support the integration of SB alone or BA+SB co-supplementation protocols into basketball-specific conditioning programs targeting repeated sprint ability and anaerobic capacity. In contrast, BA alone did not enhance short-duration maximal performance, indicating it may be better suited for sports with long-duration high-intensity efforts.

Conclusions

This study offers new insights into the effects of supplementation in highly trained female basketball players, addressing a key gap in current literature.⁵ SB alone and combined with BA supplementation were associated with improved peak power in highly trained female basketball players without impairing performance in subsequent testing. Additionally, BA+SB was associated with lower HR_{MEAN} during submaximal activity, suggesting a potential recovery benefit. In contrast, BA alone showed no performance-enhancing effects in this context. Where feasible, future studies should focus on: (1) controlling for menstrual cycle phase using hormonal verification,³⁸ (2) including male athletes to explore sex-based differences in buffering responses within basketball-specific contexts, (3) evaluating team-based performance under match-like conditions to enhance practical translation and confirm the real-world applicability of buffering strategies,³⁹ and (4) matching typical on-court rest durations, thereby more accurately reflect in-game activity patterns and improve sensitivity to buffering-related effects.

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