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Effect of Chronic Beta-Alanine Supplementation on Physical Performance and Lactate Markers in Elite Marathon Runners Living at Altitude: A Randomized Double-Blind Clinical Trial

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Abstract

This study aimed to evaluate the effect of chronic beta-alanine supplementation on physical performance and blood lactate markers in elite marathon runners living at altitude. A randomized, double-blind, placebo-controlled clinical trial with a pre–post intervention design was conducted. Twelve athletes residing at 3259-3399 m above sea level were randomly assigned to a beta-alanine group (6 g·day^{-1}; n=5) or a placebo group (n=6) for four weeks. Before and after the intervention, blood lactate markers and physical performance were assessed using a maximal incremental running test on a 400 m track. Linear mixed-effects models showed no statistically significant group x time effects for maximal lactate concentration (β=−1.29 mmol·L^{-1}; 95% CI:−4.81 to 2.23), post–rest lactate difference (β=−1.77 mmol·L^{-1}; 95% CI:−5.67 to 2.12), or lactate clearance percentage (β=−19.27%; 95% CI:−54.4 to 15.8). Similarly, no meaningful effects were observed for maximal sustained running speed (β=−0.15 km·h^{-1}; 95% CI:−2.12 to 1.82), total exercise time (β=−0.42 min; 95% CI:−2.51 to 1.67), or distance covered (β=−0.21 km; 95% CI:−0.79 to 0.36). In conclusion, four weeks of beta-alanine supplementation did not produce detectable improvements in physical performance or lactate markers in elite marathon runners living at altitude, with effect estimates indicating small and imprecise differences between groups.

Keywords: *sports performance, endurance athletes, hypoxia, sports nutrition, exercise physiology*

Introduction

Physical performance in elite marathon runners depends on a complex interaction of cardiovascular, metabolic, and neuromuscular adaptations, which are particularly relevant in contexts of training and residence at altitude. Chronic exposure to hypoxic environments induces physiological modifications aimed at optimizing oxygen transport and utilization, which may confer competitive advantages in endurance events; however, it also imposes greater metabolic stress during high-intensity exercise, accelerating the accumulation

of metabolites associated with fatigue (Bonato et al., 2023; Stellingwerff et al., 2019).

In this context, ergogenic nutritional strategies have gained a central role as a complement to training, especially in endurance athletes who live or train at altitude. Among the supplements with the strongest scientific support is beta-alanine, a non-essential amino acid that acts as the rate-limiting precursor of intramuscular carnosine. Carnosine plays key roles as an intracellular proton (H^+) buffer, a modulator of oxidative stress, and a regulator of calcium sensitivity during excitation–contraction coupling. Together, these mechanisms may attenuate exercise-induced fatigue (Brisola & Zagatto, 2019; Hostrup & Bangsbo, 2016).

Available evidence indicates that beta-alanine supplementation consistently increases muscle carnosine content, which is particularly relevant during high-intensity, moderate-duration efforts where metabolic acidosis is a limiting factor for performance (Brisola & Zagatto, 2019). In endurance athletes, several controlled trials have reported improvements in variables related to time to exhaustion, maximal aerobic speed, and performance within the aerobic–anaerobic transition zone, following both acute and chronic supplementation protocols (Huerta-Ojeda et al., 2019; Marko et al., 2025; Ojeda et al., 2023).

However, findings are not uniform. A study conducted in long-distance runners did not observe significant improvements in prolonged performance tests, such as 5-km races, despite increases in molecular markers associated with beta-alanine transport (Franco et al., 2021). These discrepancies suggest that the ergogenic effects of beta-alanine may depend on the type of exercise test, effort duration, athlete physiological profile, and the environmental context in which performance is evaluated.

In hypoxic settings, the ergogenic potential of beta-alanine is of particular interest. Reduced partial pressure of oxygen increases reliance on glycolytic metabolism and the rate of H^+ accumulation during exercise, which could theoretically amplify the benefits of enhanced intramuscular buffering capacity. However, studies evaluating beta-alanine supplementation under hypoxic conditions have reported inconsistent results, particularly in continuous endurance tests, and most have been conducted in recreationally active individuals or under simulated hypoxia models (Patel et al., 2021; Saunders et al., 2014; Wang et al., 2019).

Despite the widespread use of beta-alanine in sport, there is a lack of research examining its effects in elite marathon runners chronically residing at altitude—a population characterized by specific physiological adaptations and metabolic demands. Moreover, few studies have simultaneously integrated physical performance indicators and blood lactate markers using incremental track running protocols, limiting understanding of the mechanisms underlying a potential ergogenic response in this context.

Most of the available evidence on beta-alanine supplementation has been generated in athletes training at sea level or in recreationally active and untrained populations, frequently under laboratory-based or simulated hypoxia conditions (Brisola & Zagatto, 2019; Franco et al., 2021; Marko et al., 2025; Wang et al., 2019). These models may not accurately represent the physiological and metabolic profile of elite endurance athletes who chronically reside at high altitude, as long-term hypoxic exposure induces specific hematological, ventilatory, and metabolic adaptations that could modulate buffering requirements and lactate kinetics during exercise (Bonato et al., 2023; Stellingwerff et al., 2019). Consequently, the transferability of findings obtained in sea-level or non-elite cohorts to altitude-adapted marathon runners remains uncertain.

Therefore, the aim of the present study was to evaluate the effect of chronic beta-alanine supplementation on physical performance and blood lactate markers in elite marathon runners living at altitude, using a randomized, double-blind, placebo-controlled experimental design.

It was hypothesized that beta-alanine supplementation would improve performance indicators and lactate dynamics during a maximal incremental running test compared with placebo, since under hypoxic conditions the reduction in oxygen availability increases dependence on glycolytic metabolism and accelerates metabolic acidosis, which could theoretically amplify the ergogenic relevance of greater buffering capacity, even in athletes chronically adapted to altitude (Saunders et al., 2014; Stellingwerff et al., 2019).

Methods

Study design

A randomized, double-blind, placebo-controlled, parallel-group clinical trial was conducted, following methodological principles for experimental studies in humans and in accordance with the CONSORT guidelines for reporting randomized controlled trials. The study adopted a longitudinal pre–post intervention design with two assessment time points: before and after a four-week supplementation period (Schulz et al., 2010).

No formal sample size or power calculation was performed due to the exploratory nature of this study and the limited availability of elite marathon runners residing at high altitude. The sample size was based on comparable studies evaluating beta-alanine supplementation in endurance athletes (Franco et al., 2021; Huerta-Ojeda et al., 2019).

Participants and eligibility criteria

Participants were elite marathon runners specializing in half-marathon (21 km) and marathon (42 km) events, belonging to the National Marathon Runners Program led by the Peruvian Athletics Federation, based in the cities of Huancayo and Cusco, located at high altitude in Peru (3259–3399 m above sea level). Recruitment was conducted between January 10 and 28, 2022, on a voluntary basis and in coordination with the coaches of each training center, initially enrolling 26 athletes.

Eligibility assessment included male and female marathon runners aged 25–40 years, native residents of altitudes above 3000 m, who had not consumed beta-alanine supplements during the three months prior to the study, did not present active musculoskeletal injuries or gastrointestinal disorders, were not pregnant, and did not follow vegetarian or vegan diets.

After applying eligibility criteria, 12 marathon runners

met the requirements and were randomly assigned to the intervention groups in a 1:1 ratio. During follow-up, one participant withdrew for personal reasons unrelated to the intervention; therefore, the final analysis included 11 athletes: 5 in the beta-alanine group (BA) and 6 in the placebo group (PLA). Participant flow through the study phases is presented in Figure 1, according to the CONSORT flow diagram.

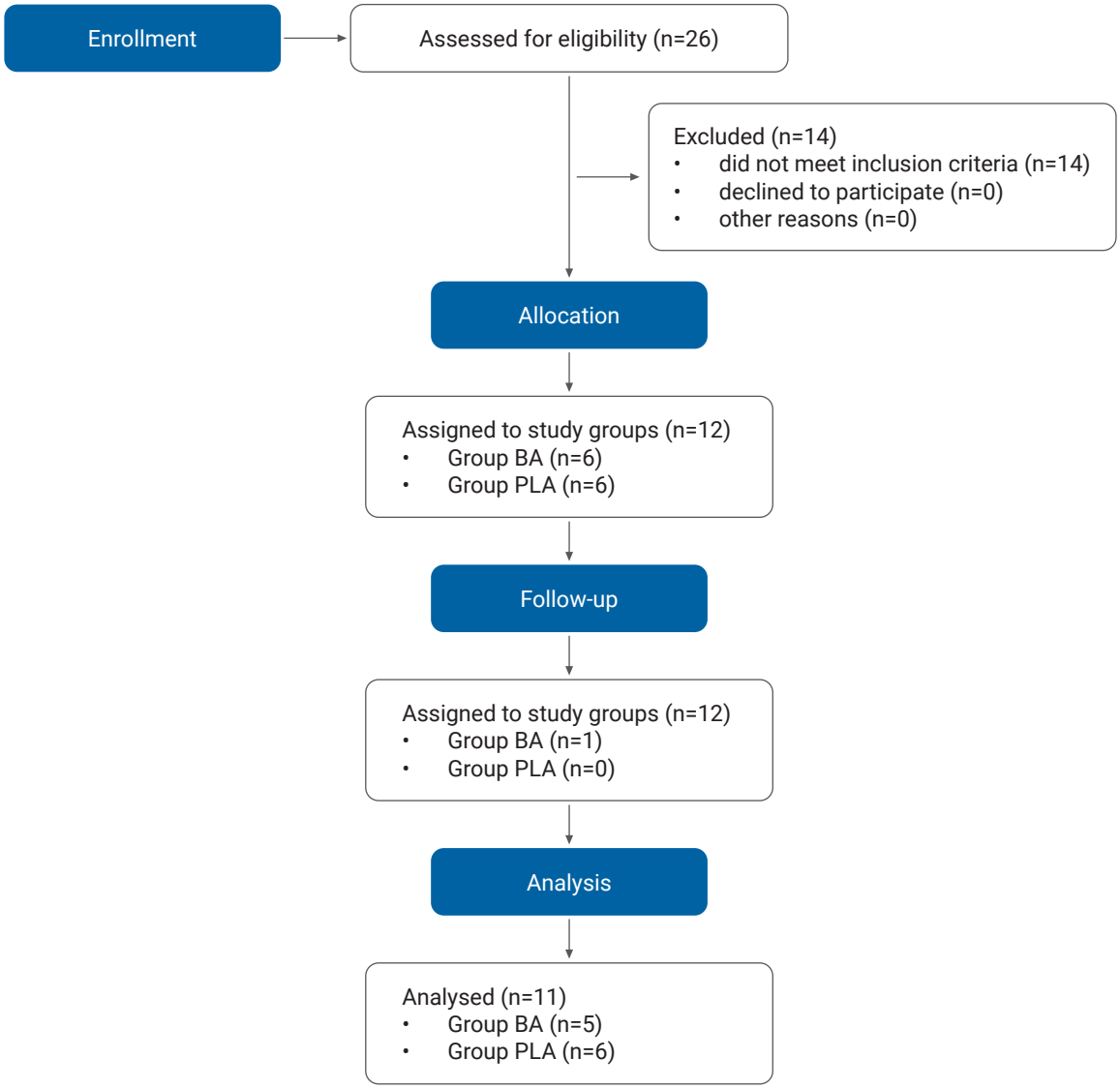

Figure 1. Flow of participants through each stage of the study

Randomization and blinding

Participants were assigned to the BA or PLA groups using simple randomization based on a computer-generated sequence. The study followed a double-blind design; participants, supplementation administrators, outcome assessors (for blood lactate, heart rate, and performance variables) and investigators responsible for data processing, and analysis were unaware of group allocation.

Supplements were encapsulated and presented in identical capsules in terms of appearance, taste, and packaging, and labeled with alphanumeric codes by an external investigator not involved in assessments or data analysis. The allocation code was disclosed only after completion of statistical analyses, ensuring maintenance of blinding throughout the intervention.

Procedures

After obtaining written informed consent, data collection was conducted at two time points (pre- and post-intervention). For both assessments, participants received standardized instructions: to consume their last meal at least 2 hours before testing, avoid strenuous exercise during the 3 hours prior, refrain from caffeine consumption for 24 hours, and maintain adequate hydration.

To standardize hydration status, participants were advised to consume approximately 30 $ml \cdot kg^{-1} \cdot day^{-1}$ of fluids during the three days preceding each evaluation, as well as 5–10 $ml \cdot kg^{-1}$ of water two hours before testing (Thomas et al., 2016; Trease et al., 2022).

Assessments were conducted between 10:00 and 13:00 h at the biomedical services of the High-Performance Centers

of the Peruvian Institute of Sport in Huancayo and Cusco. At each visit, hydration status was initially verified using the Armstrong urine color scale; in cases of hypohydration (scale 4–8), water intake was prescribed until an adequate hydration state was achieved (scale <4) before proceeding with measurements.

Anthropometry and dietary intake assessment

Body weight was measured barefoot and wearing light clothing using a digital scale (Omron Karada Scan HBF-701, Omron Healthcare Co., Ltd., Kyoto, Japan), with ±1% precision and automatic calibration. Height was measured using a stadiometer certified by the National Center for Food, Nutrition and Healthy Living (CENAN, Peru), with 0.1 cm precision. Measurements followed the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK) (Esparza-Ros et al., 2019).

Body composition was assessed by bioelectrical impedance analysis using the same digital scale. Measurements followed a standardized protocol to minimize error sources, including relative fasting, bladder voiding prior to assessment, abstinence from intense physical exercise for at least 12 hours, and avoidance of caffeine or alcohol for 24 hours. Assessments were conducted in a controlled environment and at a similar time of day for each participant, following international recommendations for bioelectrical impedance use (Kyle et al., 2004).

Dietary intake was assessed using a 24-hour dietary recall applied the day prior to each assessment (pre- and post-intervention), employing the multiple-pass method, which consists of a structured, multi-stage interview to facilitate comprehensive recall of all foods and beverages consumed. This method has demonstrated higher validity and reproducibility in adult dietary assessment (Conway et al., 2004). Portion size estimation was supported by visual aids based on auxiliary tables for dietary formulation and evaluation (Domínguez et al., 2016). Intake values were expressed as kilocalories per day and grams per day of macronutrients, and relative intake per body weight ($kcal \cdot kg^{-1} \cdot day^{-1}$ and $g \cdot kg^{-1} \cdot day^{-1}$) was used for analysis.

Supplementation protocol

Participants assigned to the BA group received a daily dose of 6 g of beta-alanine (Nutricost®, USA), divided into two 3 g doses to minimize paresthesia. The PLA group received 6 $g \cdot day^{-1}$ of maltodextrin (Nutricost®, USA) under the same administration scheme. Supplementation was maintained for four consecutive weeks, with periodic monitoring to ensure protocol adherence.

Supplement adherence was monitored by weekly follow-up calls and pill counts at the end of the intervention. Participants were instructed to report any missed doses, and adherence was defined as consuming ≥90% of the assigned capsules.

Maximal incremental running test

After a standardized 15-minute warm-up consisting of dynamic running exercises, participants performed a maximal incremental running test on a 400 m outdoor track. Male participants started at an approximate pace of 1:30 min per lap, while females started at 1:40 min per lap, with progressive speed increases each lap until voluntary exhaustion. This protocol was designed to induce controlled, progressive increases in external load in a field setting, allowing assessment of maximal performance under conditions that validly replicate the physiological and mechanical demands of endurance running at altitude (Midgley et al., 2007).

Physical performance assessment

Capillary blood lactate samples were obtained using a portable analyzer (Lactate Pro 2, Arkay Inc., Kyoto, Japan) at three standardized time points: at rest, immediately after the final lap (post), and after 3 minutes of active recovery. Samples were collected from the ear lobe to ensure consistency across participants. This allowed determination of maximal lactate concentration, post–rest lactate difference, and lactate clearance rate, calculated as the percentage reduction between maximal lactate and the value at 3 minutes post-test.

Heart rate was recorded at the end of each lap using a Polar RS800 monitor (Polar Electro Oy, Kempele, Finland), enabling estimation of mean heart rate during the test and maximal heart rate achieved at the end of the final lap. Rating of perceived exertion (RPE) was assessed at test completion using the 20-point Borg scale.

Pace (mm:ss), mean speed, and lap time were recorded to calculate maximal sustained speed, total exercise time, and total distance covered during the test.

Ethical considerations

The study was approved by the Ethics Committee of Universidad Norbert Wiener (approval code: No. 052-2021) and conducted in accordance with the ethical principles of the Declaration of Helsinki (World Medical Association, 2013), as well as the principles of scientific integrity outlined in the Singapore Statement on Research Integrity (World Conference on Research Integrity, 2010). All marathon runners provided written informed consent, and data confidentiality was ensured in compliance with Peruvian Personal Data Protection Law No. 29733.

Statistical analysis

Descriptive statistics were used to characterize baseline sample characteristics, reporting means and standard deviations (SD) for continuous variables and absolute and relative frequencies for categorical variables. Normality of continuous variables was assessed using the Shapiro–Wilk test. Baseline comparability between experimental and placebo groups was evaluated using independent-samples Student's t-tests for numerical variables.

Pre- and post-intervention changes were analyzed using linear mixed-effects regression models, accounting for the longitudinal nature of the data. These models included a random intercept at the participant level to capture within-subject correlation of repeated measurements. Study group (BA vs. PLA), time (post vs. pre), and the group × time interaction were modeled as fixed effects, with the interaction term serving as the primary parameter to estimate the effect of beta-alanine supplementation.

Mixed-effects models were preferred over paired analyses or ANCOVA due to their greater flexibility in handling individual variability. Model assumptions, including normality of residuals and homoscedasticity, were checked prior to analysis. These models can provide unbiased estimates in the presence of missing data under the missing-at-random assumption, robust standard errors were used to ensure valid statistical inference in case of deviations from assumptions.

To illustrate changes in maximal sustained speed during the maximal incremental running test on the 400 m track over time, a line graph representing group means and 95% confidence intervals was constructed. Statistical analyses were primarily conducted using SPSS software version 22.0 (IBM Corp., Armonk, NY, USA), and a p-value <0.05 was considered statistically significant.

Results

The baseline characteristics of the marathon runners included in the analysis are presented in Table 1. A total of 11 athletes completed the study, with 6 allocated to the placebo group (PLA) and 5 to the beta-alanine group (BA). Sex distribution was comparable between groups, with a similar proportion of male and female participants. Mean age was 28.5±1.8 years in the PLA group and 30.0±2.9 years in the BA group (p>0.05). No statistically significant differences were observed between groups in any of the anthropometric or body composition variables assessed at baseline (p>0.05).

These findings indicate adequate baseline comparability between the study groups prior to the intervention.

Table 1. Baseline characteristics of marathon runners by study group

Variable		PLA (n=6)	BA (n=5)	p-value
Sex		n (%)		
	Male	3	3	
	Female	3	2	
		Mean ± SD		
Age	years	28.5±1.8	30.0±2.9	0.67
Body weight	kg	54.4±2.4	56.9±5.2	0.67
Height	cm	160.6±2.1	164.6±4.2	0.42
BMI	kg/m²	21.1±0.5	20.8 ±1.0	0.82
Body fat	%	20.5±2.7	25.2±2.1	0.21
Muscle mass	%	30.5±2.2	30.1±1.3	0.88

Note. PLA = placebo group; BA = beta-alanine group; BMI = body mass index; p-value obtained using Student's t-test for independent samples.

Energy and macronutrient intake before and after the intervention is presented in Table 2. At baseline, no statistically significant differences were observed between the placebo (PLA) and beta-alanine (BA) groups in total energy intake or in body weight–adjusted protein, carbohydrate, or fat intake (p>0.05).

Throughout the intervention period, both groups maintained comparable energy and macronutrient intakes, with no relevant changes observed between the pre- and post-intervention assessments. These findings suggest that dietary intake was similar between groups and remained relatively stable over the course of the study, thereby minimizing its potential confounding effect on the performance-related outcomes evaluated.

Table 2. Energy and macronutrient intake before and after the intervention

Variable	PLA		BA		p-value
	Pre	Post	Pre	Post	
Energy (kcal·kg⁻¹·día⁻¹)	42.9±14.1	48.0±13.2	44.9±5.6	45.7±8.4	0.77
Protein (g·kg⁻¹·día⁻¹)	1.8±0.7	2.0±0.6	1.9±0.6	2.0±0.6	0.74
Carbohydrates (g·kg⁻¹·día⁻¹)	5.4±1.3	6.4±1.9	6.0±0.8	5.9±1.5	0.37
Fat (g·kg⁻¹·día⁻¹)	1.7±0.9	1.7±0.8	1.4±0.4	1.6±0.6	0.57

Note. PLA = placebo group; BA = beta-alanine group; Pre = pre-intervention; Post = post-intervention. p-value obtained using Student's t-test for independent samples (PLA-pre vs. BA-pre)

Changes in blood lactate markers before and after the intervention are presented in Table 3. No statistically significant differences were observed between the placebo (PLA) and beta-alanine (BA) groups in maximal lactate concentration achieved during the incremental test, according to the group × time interaction effect (β=−1.29mmol·L^{-1}; 95% CI:−4.81 to 2.23; p=0.42).

Similarly, no significant effects of supplementation were found for post–rest lactate difference (β =−1.77 mmol·L^{-1}; 95% CI:−5.67 to 2.12; p=0.33) or for lactate clearance percentage (β=−19.27%; 95% CI:−54.4 to 15.8; p=0.24). Overall, these results indicate that beta-alanine supplementation did not induce detectable changes in blood lactate responses during or after maximal exercise testing compared with placebo.

Table 3. Effect of beta-alanine supplementation on blood lactate markers during a maximal incremental test

Variable	PLA		BA		β (G×T)	95%IC	p-value
	Pre	Post	Pre	Post			
Lactate $_{max}$ (mmol·L^{-1})	6.5±1.7	7.1±2.0	7.9±3.1	7.1±2.8	−1.29	−4.81–2.23	0.42
Δ Lactate $_{post-rest}$ (mmol·L^{-1})	4.7±1.9	5.6±2.1	6.2±2.9	5.3±3.4	−1.77	−5.67–2.12	0.33
Lactate clearance (%)	12.9±23.4	6.5±10.3	8.5±11.2	−17.2±32.5	−19.27	−54.4–15.8	0.24

Note. PLA = placebo group; BA = beta-alanine group; max = maximum; Pre = pre-intervention; Post = post-intervention. The β (G×T) coefficient represents the group × time interaction effect (BA vs. PLA; post vs. pre). 95% CI: 95% confidence interval.

The effect of beta-alanine supplementation on physical performance variables is presented in Table 4. No statistically significant differences were observed between the placebo (PLA) and beta-alanine (BA) groups in maximal sustained running speed during the maximal incremental test, according to the group × time interaction effect (β=−0.15 km·h^{-1}; 95% CI:−2.12 to 1.82; p=0.86). Consistently, maximal sustained speed was similar between groups at both pre- and post-intervention assessments, with no significant changes over time (Figure 2).

Likewise, no significant effects of the intervention were detected on total exercise time (β=−0.42 min; 95% CI:−2.51 to 1.67; p=0.66) or on total distance covered during the test (β=−0.21 km; 95% CI:−0.79 to 0.36; p=0.42). No significant differences were observed in cardiovascular responses, including maximal heart rate achieved (β=−3.23 bpm; 95% CI:−16.6 to 10.2; p=0.59) and mean heart rate during the test (β=2.59 bpm; 95% CI:−10.0 to 15.2; p=0.65).

Furthermore, maximal rating of perceived exertion (RPE) was comparable between groups and did not show significant changes following the intervention (β=0.20; 95% CI:−1.43 to 1.83; p=0.78). Overall, these results indicate that beta-alanine supplementation did not produce detectable improvements in physical performance or in the physiological responses assessed during the maximal incremental test compared with placebo.

Table 4. Effect of beta-alanine supplementation on physical performance during a maximal incremental test

Variable	PLA		BA		β (G×T)	95%IC	p-value
	Pre	Post	Pre	Post			
Sustained speed $_{max}$ (km·h^{-1})	19.1±2.0	19.4±1.0	19.5±2.9	19.6±2.7	−0.15	−2.12–1.82	0.86
Total exercise time (min)	7.3±1.3	6.2±1.1	7.4±1.2	5.9±0.8	−0.42	−2.51–1.67	0.66
Total distance (km)	2.1±0.4	1.8 ±0.3	2.2±0.5	1.7±0.2	−0.21	−0.79–0.36	0.42
HR $_{max}$ (lpm)	165.0±9.1	165.8±6.9	167.0±11.2	164.6±7.2	−3.23	−16.6–10.2	0.59
HR $_{mean}$ (lpm)	152.5 ±12.1	154.0±7.1	151.9±5.9	156.0±10.7	2.59	−10.0–15.2	0.65
RPE $_{max}$	17.8±1.2	17.8±0.8	17.6±0.5	17.8±0.8	0.20	−1.43–1.83	0.78

Note. PLA = placebo group; BA = beta-alanine group; Pre = pre-intervention; Post = post-intervention; HR = heart rate; RPE = rating of perceived exertion; max = maximum; The β (G×T) coefficient represents the group × time interaction effect (BA vs. PLA; post vs. pre). 95% CI: 95% confidence Interval.

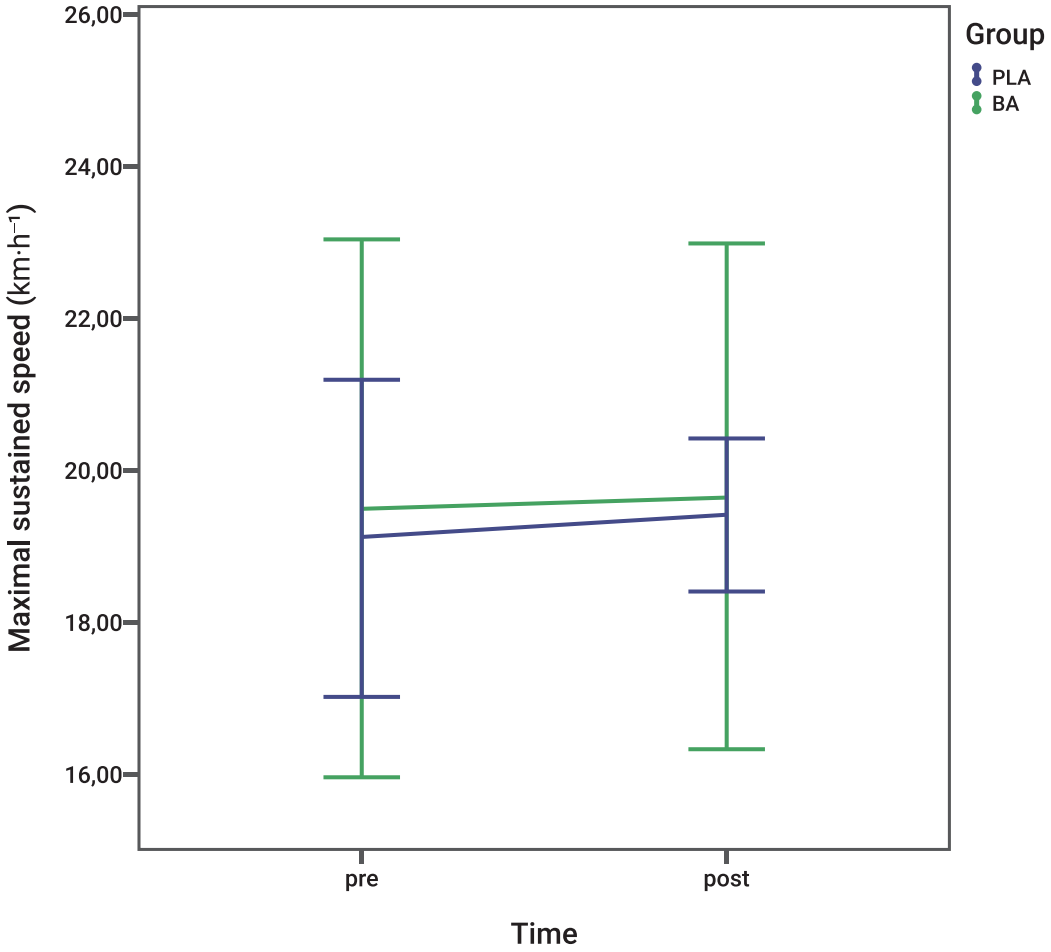

Figure 2. Maximal sustained running speed before and after the intervention in marathon runners assigned to placebo and beta-alanine

Note. Data represent group means ±95% confidence intervals. The x-axis shows time points (pre- and post-intervention), and the y-axis shows maximal sustained speed in km•h⁻¹. BA = beta-alanine group; PLA = placebo group.

Discussion

The present study evaluated the effect of four weeks of beta-alanine supplementation on physical performance and blood lactate markers in highly trained marathon runners residing at altitude, finding no significant differences compared with placebo. These null findings may be influenced by the chronic adaptations to altitude, which include enhanced oxygen delivery, altered acid-base balance, and improved metabolic efficiency, potentially overriding the additional buffering benefits provided by beta-alanine (Bonato et al., 2023; Stellingwerff et al., 2019).

These results partially contrast with studies reporting ergogenic benefits of beta-alanine in endurance athletes, particularly when acute supplementation protocols are employed or when exercise tests are conducted at intensity domains near the aerobic–anaerobic transition (Barahona-Fuentes et al., 2023; Ducker et al., 2013; Huerta-Ojeda et al., 2019; Ojeda et al., 2023). Individual variability, including the presence of non-responders, may also contribute to the heterogeneous responses observed in previous research (Hostrup & Bangsbo, 2016).

Conversely, our results are consistent with investigations that have not demonstrated clear benefits of beta-alanine supplementation in prolonged endurance performance. Franco et al. (2021) reported that four weeks of beta-alanine supplementation (4.8 g·day^{-1}) did not improve performance in a 5-km time trial in endurance runners, despite observing increased expression of the PAT1 transporter. Similarly, Patel et al. (2021) found no improvements in high-intensity exercise capacity under either normoxic or hypoxic conditions following 28 days of beta-alanine supplementation.

These findings suggest that the ergogenic effects of beta-alanine may be more pronounced in short, high-intensity efforts (1–4 minutes) rather than in long-duration endurance exercise, particularly in athletes already adapted to chronic hypoxia (Barahona-Fuentes et al., 2023; Brisola & Zagatto, 2019; Ducker et al., 2013; Huerta-Ojeda et al., 2019; Ojeda et al., 2023).

Beta-alanine, blood lactate, and metabolic buffering under chronic hypoxia

From a physiological perspective, beta-alanine increases muscle carnosine content, a dipeptide with buffering capacity against hydrogen ion accumulation during intense exercise

(Hostrup & Bangsbo, 2016). However, evidence suggests that this mechanism is more relevant during predominantly glycolytic exercise.

In the present study, no significant changes were observed in maximal lactate concentration, post–rest lactate difference, or lactate clearance percentage, which is consistent with the findings of Ducker et al. (2013). Despite reporting improved 800-m performance following beta-alanine supplementation, these authors did not observe significant changes in blood lactate concentration or post-exercise pH.

Moreover, in runners chronically adapted to altitude, prolonged exposure to hypoxia induces metabolic and ventilatory adaptations that may attenuate the additional impact of buffering supplements. In this context, Stellingwerff et al. (2019) emphasize that performance optimization at altitude relies more heavily on energy availability, iron status, and appropriate nutritional periodization than on the isolated use of ergogenic supplements.

Strengths and limitations

Among the main strengths of this study are its randomized, double-blind, placebo-controlled design, as well as the assessment conducted under ecologically valid field conditions in athletes residing at high altitude, a population that remains underrepresented in the literature.

Nevertheless, several limitations should be acknowledged. First, the small sample size limits the statistical power to detect small effect sizes. Second, muscle carnosine content was not directly measured, preventing confirmation of the biological effectiveness of the supplementation protocol. Finally, short supplementation duration that may be insufficient to induce measurable changes in highly trained athletes.

Practical implications

From an applied perspective, the results of this study suggest that chronic beta-alanine supplementation (6 g·day^{-1} for four weeks) does not provide additional benefits in physical performance or blood lactate markers in highly trained marathon runners residing at altitude. In athletes who are highly trained and chronically adapted to hypoxia, the margin for improvement attributable to supplementation appears to be limited.

Therefore, the use of beta-alanine may be more relevant in middle-distance endurance disciplines or in events involving pronounced aerobic–anaerobic transitions, as evidenced in studies involving middle-distance runners (Ducker et al., 2013; Huerta-Ojeda et al., 2019; Ojeda et al., 2023), rather than in marathon or half-marathon events.

Future research directions

Future studies should explore individualized supplementation protocols, consider combinations with other buffering agents (e.g., sodium bicarbonate), and assess effects using competition-specific performance tests. Additionally, investigating interindividual variability and the role of muscle fiber type in altitude-adapted athletes appears warranted, as suggested by Hostrup and Bangsbo (2016).

Conclusions

In the evaluated sample of highly trained marathon runners residing at altitude, beta-alanine supplementation at a dose of 6 g/day for four weeks did not produce significant improvements in physical performance assessed through a maximal incremental track test, nor in associated physiological responses, including maximal sustained speed, total exercise time, distance covered, heart rate, and perceived exertion. Furthermore, the intervention did not induce meaningful changes in blood lactate markers, such as maximal lactate concentration, lactate clearance, or post–rest variation, suggesting that beta-alanine did not substantially modify metabolic balance during maximal exercise.

For coaches and athletes, this indicates that beta-alanine may not be useful for long-distance events at altitude, though it could be relevant for shorter, high-intensity endurance activities. Importantly, these results apply specifically to highly trained marathon runners and should not be generalized to all endurance athletes.

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Conflict of Interest

The authors declare no conflicts of interest.

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