

Intra-workout carbohydrate gel containing beetroot and cajá: effects on cardiorespiratory parameters and perceived effort in cyclists

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Published online: September 30, 2026

Accepted for publication: September 15, 2026

DOI:10.7752/jpes.2026.09159

Abstract:

Introduction: During endurance exercises such as cycling, carbohydrate oxidation mainly occurs through muscle glycogen and blood glucose. Therefore, maintaining glucose levels and glycogen stores through supplementation can improve athletic performance. This study aims to assess the effects of a carbohydrate gel supplement containing beetroot and cajá on cardiorespiratory parameters and perceived exertion during indoor cycling sessions. **Methodology:** This randomized, double-blind, crossover clinical study used non-probabilistic convenience sampling and was approved by the Human Ethics Committee of the participating higher education institution. Two carbohydrate gels were tested: Gel A (20.00 g of carbohydrates and 147.69 mg of nitrates per 30 g) and Gel B (20.74 g of carbohydrates and 25.73 mg of nitrates per 30 g). Each gel was administered during two controlled 50-min indoor cycling sessions, with 30 g of gel provided every 20 min. Body composition, heart rate (HR), blood pressure (BP), and perceived effort (PE) were assessed before and after each session. Data were analyzed at a 5% significance level. **Results:** Ten male cyclists, with a mean age of 39.50 ± 11.42 years, participated in the study. The mean body mass index (BMI) was 27.57 ± 6.04 (classified as overweight), and the mean body fat percentage was $27.14 \pm 7.80\%$. A statistically significant difference in HR was observed before and after session 1 ($p = 0.0001$) and session 2 ($p = 0.002$). Only in session 2, systolic blood pressure (SBP) ($p = 0.012$) and diastolic blood pressure (DBP) ($p = 0.048$) showed a significant decrease. There were no statistically significant differences between Gel A (standard) and Gel B (developed) in terms of PE, HR, and BP values before and after both sessions. Additionally, no differences were found between the two gels regarding maximum and average HR in either workout session. **Conclusion:** Both carbohydrate gels used in this study showed similar effects on the evaluated parameters, indicating comparable efficacy in terms of cardiorespiratory response and perceived effort among cyclists.

Keywords: Cerrado fruits; Nutritional supplementation; Athletes; Sports Nutrition, Exercise physiology.

Introduction

Indoor cycling is a form of endurance exercise in which energy provision relies predominantly on oxidative metabolism, particularly during prolonged exercise (Alghannam et al., 2021). At an intensity of 40% to 50% of maximum aerobic capacity (VO₂ max), lipid oxidation predominates. However, when intensity exceeds 50% of VO₂ max, carbohydrate oxidation becomes dominant (Brun et al., 2022). As a result, inadequate hepatic glucose production combined with a decrease in blood glucose levels can lead to exercise-induced hypoglycemia, highlighting the importance of carbohydrate consumption during prolonged exercise to prevent or reverse this condition by stabilizing glucose levels (Noakes et al., 2026).

Given these energy demands and metabolic requirements, sports nutrition guidelines recommend that individuals performing this type of exercise consume 30 to 60 g of carbohydrates per hour to maintain serum glucose levels (Maughan et al., 2018), particularly under glycogen-depleted conditions (Quaresma et al., 2025). Among carbohydrate supplements, gels are convenient because they provide concentrated carbohydrates in a small volume, are easy to transport, and may minimize gastrointestinal discomfort compared with solid foods. Furthermore, there has been growing interest in developing carbohydrate supplements formulated with natural ingredients, providing bioactive compounds (Parente et al., 2025).

Beetroot (*Beta vulgaris* L.) is a promising ingredient for this purpose; it contains carbohydrates such as sucrose (33 to 40.79 g/100 g) and glucose (2.24 to 3.84 g/100 g) (Almeida et al., 2025). In addition to its carbohydrate content, beetroot is considered a good source of nitrate (>2500 mg/kg), which has been widely investigated for its ergogenic potential (Milton-Laskibar et al., 2021).

Dietary nitrate (NO₃⁻) is reduced to nitrite (NO₂⁻) and subsequently converted into nitric oxide (NO), increasing NO availability and contributing to vascular and skeletal muscle responses relevant to exercise (Zhou

et al., 2024). Increased NO availability may improve vasodilation, microvascular perfusion, and oxygen delivery to active tissues through mechanisms involving soluble guanylate cyclase and cyclic guanosine monophosphate signaling (Yin et al., 2023; Lee et al., 2026).

These responses may also improve muscle and mitochondrial efficiency, potentially reducing the oxygen cost of exercise and contributing to greater exercise tolerance (Lee et al., 2026). However, the ergogenic response to dietary nitrate is not uniform and may vary according to exercise modality, training status, dose, and supplementation strategy (Senefeld et al., 2020; Poon et al., 2025).

In recent years, supplement consumers have been seeking products developed with natural or organic ingredients, or those with low to zero additive content, products referred to as clean label (Lenz et al., 2022). In this context, cajá (*Spondias mombin* L.), a fruit native to the Brazilian Cerrado, is an attractive ingredient: Its pulp contains naturally occurring sugars (4.54 ± 0.25 g/100 g) and is also a source of vitamin C and carotenoids, including provitamin A (Mattietto et al., 2010; De Sousa et al., 2024). Furthermore, incorporating native Brazilian fruits into supplements, such as cajá, may increase their commercial value, thereby benefiting family farming and promoting sustainability (Barbosa et al., 2024).

Recently, Da Silva et al. (2026) developed carbohydrate gels formulated with beetroot and açai—a fruit native to Brazil—and compared them with a commercial formulation that also contained beetroot but relied on artificial flavorings.

The developed formulations outperformed the commercial product in terms of appearance, color, and texture. Although this study demonstrated the technological feasibility and sensory acceptability of natural beetroot-based carbohydrate gels, no physiological evaluation was performed.

Although carbohydrate supplementation during endurance exercise is well established and dietary nitrate has been extensively investigated using beetroot juice and inorganic nitrate supplements (Hoon et al., 2013; McMahon et al., 2017), comparatively less evidence is available regarding carbohydrate gels formulated with natural ingredients that simultaneously provide carbohydrates and dietary nitrate during exercise. Moreover, evidence regarding formulations incorporating native Brazilian fruits, such as cajá, remains scarce. Therefore, evaluating a beetroot-cajá carbohydrate gel under exercise conditions may contribute to the development of innovative functional supplements while expanding the scientific evidence supporting biodiversity-based ingredients in sports nutrition.

Thus, the present study aimed to evaluate the effects of a carbohydrate gel formulated with beetroot and cajá on cardiorespiratory parameters and perceived exertion during indoor cycling, and to compare it with a commercially available beetroot-based carbohydrate gel. We hypothesized that the developed formulation would produce physiological responses comparable to those of the commercial product while providing a natural, functional alternative based on Brazilian ingredients for carbohydrate supplementation during endurance exercise.

Materials & methods

Study design and ethical aspects

This study was designed as a crossover randomized, double-blind clinical trial with non-probabilistic convenience sampling. It was approved by the Ethics Committee of the Federal University of Mato Grosso do Sul (approval no. 5,537,145, CAAE 56187822.1.0000.0021).

The study included male adult cyclists (over 18 years old) who cycled regularly three times or more per week, were willing to participate, and signed an informed consent form (IC), as required by Resolution no. 466/2012 of the Ministry of Health (2012). Participants diagnosed with conditions that could affect cardiorespiratory parameters—such as hypertension, cardiovascular and/or respiratory diseases—or those with allergies or food intolerances to any ingredient in the developed product or the pre-workout meal were excluded.

Nutritional intervention

The intervention consisted of two days of 50-minute indoor cycling sessions, during which participants consumed a standard commercial gel (Gel A) and a carbohydrate gel developed by the authors from the same research group (Study Group on Nutrition in Sports, Health, Research, and Innovation - GENESPI/UFMS) containing beetroot and cajá (Gel B).

The gels were consumed every 20 minutes during training, with each serving being 30 g, providing a total of 40 to 41.5 g of carbohydrates per session, in line with recommendations by the International Society of Sport Nutrition (Kerksick et al., 2018).

Gel A contained 20.00 g of carbohydrates and 147.68 mg of nitrate per 30 g serving, while Gel B contained 20.74 g of carbohydrates and 25.73 mg of nitrate per 30 g serving. The carbohydrate content of both gels was statistically equivalent; however, Gel A had a higher nitrate concentration.

The gels were administered in a randomized and double-blind manner using coded packaging. Training sessions were spaced one week apart to allow crossover between the two gels, as illustrated in Figure 1.

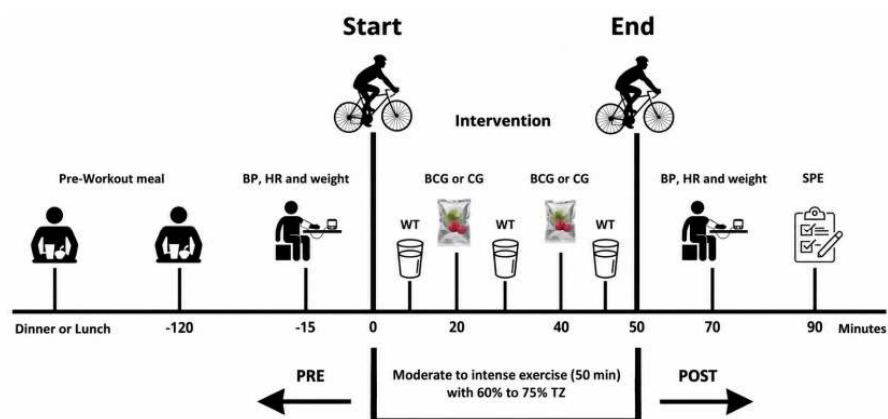


Figure 1. Intervention design. BP = blood pressure, HR = heart rate, BCG = beetroot carbohydrate gel, CG = control gel, TZ = training zone, SPE = subjective perception of effort, WT = water. Source: Prepared by the authors (2024).

Blood pressure, heart rate, and perceived effort were assessed before and after each session. The study was conducted at the UFMS School Gym. Participants were instructed not to alter their usual eating habits or engage in exercise the day before the sessions and were required to wear appropriate clothing. Detailed guidance was provided at each stage, as outlined below.

Participants

The initial sample included 27 male cyclists. Of these, 14 were lost to follow-up due to time constraints. Of the remaining 13 participants, three were excluded because they did not maintain the heart rate required for moderate to high - intensity training or due to errors in obtaining data from the equipment (Polar® H10; Polar® M460). The final sample consisted of ten cyclists, five of whom did not attend the second training session.

Standardization of pre-workout meals

An acute carbohydrate loading strategy was employed to maintain glycogen reserves, following the guidelines of the International Society of Sport Nutrition (Kerksick et al., 2018): 5 to 8 g/kg of carbohydrates 24 hours before training and 1 to 4 g/kg between 1 and 4 hours before exercise. The following standardization was implemented: 1.25 to 1.3 g/kg of carbohydrates at dinner the day before or at lunch on the day of the session (depending on the timing of each participant's intervention), corresponding to 25% of daily carbohydrate needs, and 1.3 g/kg of carbohydrates 1 to 2 hours before the session.

Individualized menus were provided for standardized lunch or dinner. These menus accounted for potential body weights between 50 and 130 kg, delivering the prescribed carbohydrate amounts in g/kg of body weight. Participants were provided with the menu most closely aligned with their current weight and a list of acceptable substitutions. The immediate pre-workout meal consisted of powdered milk, chocolate milk, and maltodextrin. Participants were advised to avoid pre-workout supplements and foods high in nitrate and caffeine to avoid interference with the results (Assis, 1997).

Cyclist profile and body composition assessment

Information about participants' cycling profiles, including frequency and session duration in hours, was collected via a Google Forms questionnaire. Body composition was assessed using bioimpedance analysis (InBody S10®), which evaluates body water, body fat percentage, lean mass, and BMI based on previous data on age, weight, and height.

Assessments took place at the Nutritional Assessment and Body Composition Laboratory of FACFAN/UFMS. Participants were instructed to fast for four hours, empty their bladders, avoid wearing metal or insulated accessories, refrain from exercising the day before, and abstain from alcohol and caffeinated beverages for at least eight hours prior to the exam (Eickemberg et al., 2011). Body fat percentage was classified according to Lohman's reference (1992) for males: 6 to 14% (below average), 15% (average), 16 to 24% (above average), and 25% (very high).

Assessment of cardiorespiratory parameters and perceived effort

Blood pressure and heart rate were measured before (after at least five minutes of rest) and ten minutes after each session using a digital sphygmomanometer (G-tech, GP 400®) and a heart rate monitor with a chest strap and cycle computer (Polar® H10; Polar® M460). Participants were seated with legs uncrossed, backs supported, and arms resting on a table with palms facing upward. Blood pressure and heart rate were measured four times with a one-minute interval between measurements (Bezerra et al., 2019).

Heart rate during exercise was monitored to ensure it remained within the target training zone of 60 to 75%, as calculated for each participant using the Karvonen (1957) formula: $THR = \% (HR_{max} - HR_r) + HR_r$, where $HR_{max} = 220 - \text{age}$, HR_r is the resting heart rate, and % is the desired effort percentage (Marins et al., 1998). The target range of 60% (weight control zone) to 75% (aerobic zone) was deemed appropriate for training sessions lasting 30 to 60 minutes or longer (Fernandes Filho, 1999). The perceived effort (PE) was assessed 30 minutes after training using the adapted OMNI Scal (Robertson et al., 2004).

Statistical analysis

Data were analyzed using SPSS (Statistical Package for the Social Sciences, IBM Corp., USA) version 20.0. Descriptive statistics were presented as mean, standard deviation, and absolute and relative frequencies. The normality of the variables was assessed using the Shapiro-Wilk test. Paired t-tests were used to compare cardiorespiratory parameters before and after training sessions, while Student's t-test and the Mann-Whitney test were used to compare the effects of the different gels used in the nutritional intervention, considering a 5% significance level ($p < 0.05$).

Results

Cyclist profile and body composition assessment

Among the participants ($n = 10$), 62.5% identified as amateur athletes, 25% as sports enthusiasts, and 12.5% as professional athletes. A total of 87.5% had been cycling for more than 12 months; 37.5% cycled five times or more per week; 50% engaged in training sessions lasting between one and two hours, while the other 50% trained for between two and five hours per session.

Regarding body mass index (BMI, kg/m^2) 30% of the participants were classified as eutrophic and 60% as overweight, according to the World Health Organization classification referenced by Anjos (1992).

In terms of body fat percentage (%BF), 90% of the cyclists were found to have a high body fat percentage. Specifically, 50% were classified as being at risk for cardiovascular diseases ($\%BF \geq 25$), and 40% were classified as above average (%BF between 16 and 24). Only 10% of the participants had a body fat percentage within the expected range, which is between 6 and 15% (Lohman, 1992). Table 1 presents additional parameters that were evaluated.

Table 1. Assessment of cyclists' body composition.

Parameters	Mean $\pm$ SD (n = 10)
Weight (kg)	81.87 $\pm$ 14.57
Height (cm)	172.88 $\pm$ 6.34
BMI (kg/m^2)	27.57 $\pm$ 6.04
Total Body Water - TBW (L)	43.33 $\pm$ 5.38
Intracellular Water (L)	26.99 $\pm$ 3.41
Extracellular Water - EW (L)	16.34 $\pm$ 1.98
Body Fat Percentage (%)	27.14 $\pm$ 7.80
Lean Mass (Kg)	55.71 $\pm$ 6.93

Source: Prepared by the authors (2024).

Assessment of cardiorespiratory parameters and perceived effort

Table 2 presents the results of the assessment of cardiorespiratory parameters and the perceived effort among the cyclists. A comparison of heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) before and after sessions 1 and 2 revealed a statistically significant difference in HR before and after session 1 ($p = 0.000$) and session 2 ($p = 0.002$).

There was also a significant difference in SBP before and after session 2 ($p = 0.012$) and in DBP before and after session 2 ($p = 0.048$). However, no statistically significant differences were found between SBP before and after session 1 ($p = 0.082$) or between DBP before and after session 1 ($p = 0.444$).

Table 2. Pre- and post-workout cardiorespiratory parameters and perceived effort

Parameters	Session 1 (n = 10)			Session 2 (n = 5)		
	Pre Mean $\pm$ SD	Post Mean $\pm$ SD	p-value*	Pre Mean $\pm$ SD	Post Mean $\pm$ SD	p-value*
HR (bpm)	72.85 $\pm$ 13.97b	88.20 $\pm$ 13.17a	0.0001	69.69 $\pm$ 16.55b	87.98 $\pm$ 14.95a	0.002
SBP (mmHg)	155.30 $\pm$ 21.54	143.78 $\pm$ 15.16	0.082	139.50 $\pm$ 10.62a	130.91 $\pm$ 7.68b	0.012
DBP (mmHg)	91.45 $\pm$ 8.46	88.68 $\pm$ 9.31	0.444	86.50 $\pm$ 5.74a	79.94 $\pm$ 7.90b	0.048
PE	-	3.80 $\pm$ 2.49	-	-	3.69 $\pm$ 2.43	-

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; PE = perceived effort.

*Paired t test. Source: Prepared by the authors (2024).

Regarding the perceived effort, participants rated the training as “easy” or “a little easy” according to the scale used in this study (Robertson et al., 2004).

Table 3 presents the comparison of carbohydrate gels with respect to cardiorespiratory parameters. There were no statistically significant differences between consuming Gel A (the standard gel containing 20.00 g of carbohydrates) and Gel B (the gel containing beetroot and cajá with 20.74 g of carbohydrates) in terms of pre- and post-workout heart rate, maximum heart rate, average heart rate, minimum heart rate, or blood pressure measurements taken before and after sessions 1 and 2.

Parameters	Session 1 (n = 10)			Session 2 (n = 5)		
	Gel A (n=5)		p-value*	Gel A (n=2)		p-value*
	Mean±SD	Mean±SD		Mean±SD	Mean±SD	
HR pre (bpm)	69.20±12.49	76.50±15.80	0.441	69.13±13.19	70.25±21.54	0.932
HR post (bpm)	88.65±13.78	88.75±14.13	0.921	86.15±14.18	89.81±17.65	0.756
HR maximum	154.40±11.08	164.20±4.32	0.499	163.50±6.36	150.67±13.32	0.565
HR average	140.40±13.18	144.20±12.95	0.658	149.00±2.83	143.33±17.47	0.695
HR minimum	130.20±10.57	142.00±5.09	0.103	139.00±0.00	125.33±11.06	0.308
SBP pre (mmHg)	159.50±7.28	151.10±30.77	0.581	135.94±10.52	143.06±10.87	0.383
SBP post (mmHg)	141.90±7.60	145.66±21.23	0.719	132.00±7.06	129.81±9.21	0.719
DBP pre (mmHg)	93.80±4.98	89.10±11.07	0.412	84.63±6.60	88.38±4.89	0.397
DBP post (mmHg)	84.05±8.17	88.68±9.13	0.120	77.00±5.05	82.88±9.85	0.329

Table 3. Comparison of the consumption of gels A and B in relation to cardiorespiratory parameters and perceived effort (PE) during cyclists' training

HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; Gel A (standard gel - (20.00 g of carbohydrate and 147.68 mg of nitrate per 30 g); Gel B (gel containing beetroot and cajá: 20.74 g of carbohydrate and 25.73 mg of nitrate per 30 g) *Student's t-test. Source: prepared by the authors (2024).

Table 4 summarizes the variables related to heart rate (maximum, average, and minimum), %HR max., temperature, and relative humidity during training sessions 1 and 2. The maximum heart rate recorded during session 1 was 161.90±10.85 bpm, and during session 2, it was 169.30±8.64 bpm. The minimum heart rates recorded for both sessions 1 and 2 were the same, with no significant difference between them (p = 1.000). The average heart rates were 159.30±9.46 bpm for session 1 and 145.60±12.82 bpm for session 2, with session 1 showing a statistically higher average (p = 0.025).

Participants achieved an average of 67.09±5.61% of their maximum heart rate during session 1 and 70.59±9.50% during session 2, with no statistically significant difference between the sessions (Table 4).

Regarding the temperatures before and after sessions 1 and 2, no statistically significant differences were observed; the averages ranged from 24.88±1.46 to 26.50±1.84 °C. However, there was a statistically significant difference in relative humidity between pre- and post-training measurements for both training sessions (Table 4).

Table 4. Results for heart rate (maximum, average, and minimum), %HR max., temperature, and relative humidity during sessions 1 and 2.

Parameters	Session 1 (n=10)	Session 2 (n=5)	p-value*
	Mean±SD	Mean±SD	
HR maximum (bpm)	161.90±10.85	169.30±8.64	1.000
HR average (bpm)	159.30±9.46a	145.60±12.82b	0.025
HR minimum (bpm)	136.10±9.99	136.10±9.99	1.000
%HR maximum de session	67.09±5.61	70.59±9.50	0.208
Temperature (°C; Pre-session)	26.10±2.85	24.88±1.46	0.644
Temperature (°C; post-session)	26.50±1.84	25.50±2.00	0.443
Relative humidity (%; Pre-session)	70.40±9.82b	84.88±6.77a	0.048
Relative humidity (%; post-session)	69.10±7.20b	81.63±7.96a	0.026

HR = heart rate. *Paired t test. Source: Prepared by the authors (2024).

Discussion

The results of this study indicate that there was no significant difference in the intra-workout use of carbohydrate supplementation between Gel A (standard) and Gel B (a developed gel containing beetroot and cajá) for the evaluated parameters.

Given that carbohydrates are the main constituents of the nutritional composition of these gel supplements, it is important to discuss their sources. The standard gel contains carbohydrates such as tapioca syrup or isomalto-oligosaccharide (a prebiotic) and isomaltulose (palatinose), both of which have a low glycemic index (Agricola et al., 2021; Sorndech et al., 2018). In contrast, the formulated gels contain high glycemic index carbohydrates, such as maltodextrin and sucrose (Liu et al., 2021).

A high glycemic index indicates that the carbohydrate is quickly digested and used as an energy source (Lisnawati et al., 2023). For instance, maltodextrin is rapidly absorbed in the intestine (Carvalho & Alfenas, 2008). Conversely, low glycemic index carbohydrates are digested more slowly, leading to a reduced impact on blood sugar levels due to their slower absorption rate (Lisnawati et al., 2023).

Besides the glycemic index, the use of carbohydrates during exercise can increase the level of oxidation if multiple transporters are activated through different sources, such as the combination of sucrose and fructose (Malone et al., 2021). Both the developed gel and the commercial standard gel presented this combination. The standard gel had a higher fructose content (4.15 ± 0.64 g vs. 1.60 ± 0.14 g in F1) but a lower sucrose content than the developed gel (1.70 ± 0.99 g vs. 20.35 ± 0.92 g in F1). However, there was no difference in the total carbohydrate content between them.

Consuming high levels of carbohydrates from different sources or types can lead to oxidation rates of up to 1.75 g of carbohydrate per minute, compared to 1 g per minute when using the same type of carbohydrate. This is due to the utilization of more transporters and reduced saturation of a single transporter (Malone et al., 2021). For example, SGLT-1 transporters are required for glucose and galactose uptake, while GLUT-5 is required for fructose uptake. SGLT-1 transporters are more abundant than GLUT-5, resulting in greater glucose absorption in the intestine compared to fructose. Thus, the concurrent consumption of various types of carbohydrates can activate SGLT-1, GLUT-5, GLUT-2 (transport to the hepatic portal system), and GLUT-4 (insulin-dependent glucose transport in muscle (Malone et al., 2021). A study that examined the use of palatinose and maltodextrin in electrolyte drinks at an 8% concentration (20 g/h) in a volume of 4.5 to 6 ml/kg of body weight, as well as a placebo drink, during a 120-minute soccer training session, found that the glucose peak for palatinose ingestion occurred between 75 and 90 minutes of training, while for maltodextrin, it was at 50 minutes (Stevenson et al., 2017).

At 60 minutes, the decline in glycemia was greater for maltodextrin (Stevenson et al., 2017), which may suggest that for longer workouts, palatinose use is more suitable, whereas maltodextrin may be more effective for shorter workouts. However, the literature shows that maltose, sucrose, maltodextrin, and glucose polymers have very similar rates of exogenous oxidation compared to glucose (Stevenson et al., 2017).

The energy substrate used in physical exercise varies according to exercise intensity. During low-intensity exercises, which reach 45 to 55% of VO_2 max and 60 to 70% of maximum heart rate, fat is the primary substrate for energy production. During moderate to intense exercises, ranging from 70 to 90% of maximum heart rate and 55 to 80% of VO_2 max, both fat and carbohydrates are utilized, with carbohydrates being predominant in high-intensity exercises ($> 80\%$ of VO_2 max and $> 90\%$ of maximum heart rate) (Tebexreni et al., 2009; Skinner & McLellan, 1980).

Kerksick et al. (2018) classifies exercises as intense when they reach more than 70% of VO_2 max and recommends supplementation with electrolyte drinks containing 8% carbohydrates or the use of carbohydrate gels, particularly in the absence of a pre-training nutritional strategy.

A study by Abbiss et al. (2008) demonstrated a positive effect of carbohydrate supplementation during moderate to high-intensity exercises when associated with high ambient temperatures. In this study, the application of a carbohydrate gel rich in sucrose and a placebo gel (composition not disclosed) was tested on ten male cyclists in four experimental trials at temperatures ranging from 18 to 32 °C. Each trial involved 90 minutes of cycling at moderate intensity (60% of VO_2 max), followed by a

16.1 km time trial. Power output decreased more in the highest temperature conditions (32 °C), while carbohydrate ingestion improved the 16.1 km time trial performance time in hot conditions but not in cooler temperatures (18 °C). Additionally, carbohydrate ingestion favored greater power output during the final 2 km of the sessions at both temperatures (Abbiss et al., 2008).

Although the controlled training sessions in this study were of moderate to high intensity (60 to 75%) (Alghannam et al., 2021; Tebexreni et al., 2009), with participants reaching 67.09% in session 1 and 70.59% in session 2 of maximum heart rate, these findings differ from the aforementioned study due to the strategy of acute carbohydrate replenishment before training to maintain glycogen stores. Typically, muscle glycogen stores contain 300 to 400 mmol/kg, but dietary strategies can increase this figure to 700 to 900 mmol/kg. Although higher glycogen reserves lead to greater glycogen degradation during exercise (Alghannam et al., 2021), increased stores can delay the onset of fatigue (Kerksick et al., 2018).

The pre-workout carbohydrate replenishment strategy, combined with the supplementation of 60 g of gel (A or B) over a period of 50 minutes, suggests that both gels had a positive impact on the evaluated parameters, as no statistical differences were observed between them. Furthermore, the gels were effective in preventing fatigue and, consequently, in avoiding impairments to sports performance, which was reflected in the cyclists' perception that the training sessions were "easy" or "a little easy" (Robertson et al., 2004). The environmental conditions may have also contributed, with average temperatures ranging from 24.9 to 26.5 °C and average relative humidity between 69.1 and 84.9% during both training sessions.

Another important component of carbohydrate gels A and B is nitrate. Although the manufacturer considers Gel A as nitrate-free, previous physicochemical analyses revealed levels of 147.69 mg of nitrate in Gel A and 25.73 mg in Gel B (in the 30 g portion).

In this study, the objective was to evaluate the application of an intra-workout carbohydrate gel and compare it with a commercially available gel containing similar ingredients. Therefore, the nitrate present in the gels did not significantly affect the cardiovascular parameters evaluated, as nitrate is typically recommended for

ergogenic purposes at levels of 310 to 560 mg, consumed two to three hours before training or through chronic use (more than three days) (Brun et al., 2022), as discussed below.

A study involving thirteen male runners examined the effects of chronic consumption of beetroot juice (420 ml) at a concentration of 8.4 mmol of nitrate versus a placebo (420 ml of beetroot juice with depleted nitrate) over three days. The maximum heart rate (HR_{max}) showed no significant difference between placebo and beetroot juice consumption in terms of heart rate ($p = 0.673$) when evaluating maximum VO₂ and peak velocity ($p = 0.883$) (Alexandri et al., 2022).

Another semi-randomized crossover study with 11 men and seven women, who exercised up to ten hours per week, assessed four different drinks, each containing 800 mg of nitrate, one of which was concentrated beet juice. Blood pressure was measured before and up to 300 minutes after consumption, without any associated physical exercise. Systolic blood pressure decreased 150 minutes after beetroot juice ingestion (from 118.6 ± 2 to 113.6 ± 2 mmHg; $p < 0.001$), and diastolic blood pressure decreased 150 minutes after the ingestion of all beverages ($p < 0.05$) (Pesova et al., 2023). The study by Agricola et al. (2021) evaluated blood pressure and heart rate before and after a 30-minute indoor cycling training session at moderate intensity (70% of heart rate). It reported an increase in heart rate (from 77 to 97 bpm), no significant change in diastolic blood pressure (from 74 to 73 mmHg), and an increase in systolic blood pressure (from 134 to 139 mmHg) (Castro et al., 2018).

In the present study, the findings were partially consistent with the literature. Heart rate increased after training, systolic blood pressure decreased in session 2, and diastolic blood pressure remained unchanged in session 1 but decreased in session 2, with no significant differences observed between the consumption of Gel A (standard) and Gel B (containing beetroot and cashew) concerning these parameters. These effects were likely due to the training itself, as an increase in heart rate, a decrease in systolic blood pressure, and stabilization or slight decrease in diastolic blood pressure after training are expected in aerobic exercises such as indoor cycling (Jonvik et al., 2016).

Regarding the participants' body composition, physical exercise, combined with dietary and supplementation strategies, can have a direct impact. Participants had an average BMI of 27.57 kg/m^2 , classified as overweight Anjos (1992), and a body fat percentage of 27.14%, which is above the ideal recommendation (Lohman, 1992), indicating a potential health risk.

It is important to note that BMI analysis has limitations, such as not differentiating between fat and lean body mass. This can lead to incorrect classification if an individual has higher muscle or bone mass. BMI is also not suitable for use in specific populations (Wu et al., 2024). In this study, body composition was analyzed using several parameters, including BMI and electrical bioimpedance. The percentage of body fat obtained from bioimpedance corroborates the BMI classification of overweight participants, as it indicates not only excess weight but also excess body fat.

A higher BMI is generally associated with a sedentary lifestyle and an unbalanced diet (Wu et al., 2024). However, 37.5% of the participants in this study exercised five times or more per week, 50% exercised one to two hours per session, and 50% exercised between two to five hours per week. This indicates that their lifestyle was not sedentary, suggesting that other factors may contribute to their body composition.

The study by Herdy et al. (2020) evaluated 30 under-20 soccer players using bioimpedance and found a body fat percentage of 11.74%, classified as below average (Jonvik et al., 2016), with muscle mass at 37.03%. In another study by Guimarães et al. (2022) which evaluated cyclists (aged 45.02 ± 10.24 years, both men and women) using the seven-fold protocol of Jackson and Pollock (1978), only 8.1% of cyclists had a high body fat percentage. The participants in the present study had an average body fat percentage of 27.14%, with an expected range of 6 to 15% for men (Lohman, 1992), showing a divergence from the presented literature.

Conclusions

The present study demonstrated that the carbohydrate gel formulated with beetroot and cajá elicited physiological responses comparable to those of a commercially available beetroot gel during indoor cycling. Furthermore, there were no significant differences in the cardiorespiratory parameters evaluated or in the perception of effort between participants consuming commercial Gel A and those consuming Gel B. These findings suggest that a formulation based on natural ingredients can support physiological responses to the same extent as a commercial product currently available on the Brazilian market.

These findings contribute to the emerging evidence supporting the development of sports nutrition products based on natural and regionally sourced ingredients. The use of beetroot and cajá demonstrates the feasibility of incorporating Brazilian biodiversity into carbohydrate supplements while maintaining the expected acute cardiorespiratory and perceptual responses during exercise. In this sense, the study provides both scientific and technological support for the development of clean-label sports nutrition products that combine nutritional functionality with the use of native ingredients.

From a practical perspective, the developed gel may represent a viable alternative for athletes, sports nutrition professionals, and manufacturers interested in natural carbohydrate supplements for endurance exercise. Its comparable responses to a commercial product, together with the use of beetroot and cajá, reinforce its

potential for application in sports nutrition and for the development of innovative products based on Brazilian raw materials.

Although beetroot is a natural source of dietary nitrate, the present study was not designed to evaluate nitrate-specific ergogenic mechanisms, and the nitrate content of the developed gel was lower than that of the commercial product. Future studies should therefore investigate the developed formulation under protocols specifically designed to assess nitrate-related effects, including pre-exercise or chronic supplementation, higher-intensity or longer-duration exercise, and different glycogen availability conditions. Studies involving larger and more diverse athletic populations, as well as direct measures of exercise performance, metabolic responses, and biomarkers related to nitric oxide metabolism, may clarify the potential functional effects of the formulation and strengthen its scientific and commercial applicability.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist with the organization and formatting of the reference list. After using this tool, the authors carefully reviewed and verified all references and edited the manuscript as necessary. The authors take full responsibility for the accuracy and content of the publication.

Conflicts of interest

The authors declare no conflicts of interest.

Funding source

This work received support and funding from the Foundation for the Support of the Development of Education, Science and Technology of the State of Mato Grosso do Sul (FUNDECT), through call for proposals no. 31/2021-ODS.

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