

# ACUTE EFFECTS OF GUARANA ON PHYSIOLOGICAL RESPONSES, EXERTION, AND PERFORMANCE: A SYSTEMATIC REVIEW AND META-ANALYSIS

*EFEITOS AGUDOS DO GUARANÁ NAS RESPOSTAS FISIOLÓGICAS, NA PERCEPÇÃO DE ESFORÇO E NO DESEMPENHO EM EXERCÍCIOS: UMA REVISÃO SISTEMÁTICA E META-ANÁLISE*

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**ABSTRACT:** We conducted a systematic review and meta-analysis to evaluate the acute effects of guaraná supplementation or guarana-containing compounds on physiological responses, perceived exertion, and exercise performance in healthy adults. This review (CRD42021249569) followed Cochrane recommendations, with searches performed in PubMed, Web of Science, Embase, SportDiscus, and BIREME. Data from included studies were synthesized, and risk of bias was assessed using the RoB-2 tool. Outcomes included: (1) perceived exertion; (2) exercise performance parameters—peak power output (PPO), fatigue, speed, strength, total work, and vertical jump height; and (3) physiological parameters—heart rate (HR), respiratory exchange ratio (RER), maximal oxygen uptake ( $VO_{2max}$ ), peak oxygen uptake ( $VO_{2peak}$ ), glucose, and lactate threshold. Meta-analysis showed a significant reduction in perceived exertion (SMD: -1.32; 95% CI: -1.85 to -0.79;  $p = 0.01$ ;  $I^2 = 36\%$ ), with no effect on HR (SMD: -0.18; 95% CI: -0.77 to 0.42;  $p = 0.56$ ;



$I^2 = 0\%$ ). Qualitative findings indicated reductions in fatigue (25.30%), increases in PPO during anaerobic exercise (2.57%), and improvements in total work performed (4%). No significant effects were observed for PPO in aerobic exercise,  $VO_{2max}$ ,  $VO_{2peak}$ , glucose, RER, lactate threshold, vertical jump, or agility. In conclusion, guarana supplementation may reduce perceived exertion (with a large effect size), decrease fatigue, and enhance anaerobic performance and total work during cycling, without adverse effects on HR.

**KEYWORDS:** Functional food. Physical functional performance. Exercise.

**RESUMO:** Realizamos uma revisão sistemática com meta-análise para avaliar os efeitos agudos da suplementação de guaraná ou de compostos contendo guaraná nas respostas fisiológicas, na percepção de esforço e no desempenho físico em adultos saudáveis. Esta revisão (CRD42021249569) seguiu as recomendações da Cochrane, com buscas realizadas nas bases PubMed, Web of Science, Embase, SportDiscus e BIREME. Os dados dos estudos incluídos foram sintetizados, e o risco de viés foi avaliado por meio da ferramenta RoB-2. Os desfechos analisados incluíram: (1) percepção de esforço; (2) parâmetros de desempenho—potência de pico (PPO), fadiga, velocidade, força, trabalho total e altura do salto vertical; e (3) parâmetros fisiológicos—frequência cardíaca (FC), razão de troca respiratória (RER), consumo máximo de oxigênio ( $VO_{2máx}$ ), consumo de oxigênio de pico ( $VO_{2pico}$ ), glicose e limiar de lactato. A meta-análise demonstrou redução significativa na percepção de esforço (SMD: -1,32; IC 95%: -1,85 a -0,79;  $p = 0,01$ ;  $I^2 = 36\%$ ), sem efeito sobre a frequência cardíaca (SMD: -0,18; IC 95%: -0,77 a 0,42;  $p = 0,56$ ;  $I^2 = 0\%$ ). A análise qualitativa indicou redução da fadiga (25,30%), aumento da potência de pico em exercícios anaeróbios (2,57%) e incremento no trabalho total realizado (4%). Não foram observados efeitos significativos sobre a PPO em exercícios aeróbios,  $VO_{2máx}$ ,  $VO_{2pico}$ , glicose, RER, limiar de lactato, salto vertical ou agilidade. Em conclusão, a suplementação de guaraná pode reduzir a percepção de esforço (com grande tamanho de efeito), diminuir a fadiga e melhorar o desempenho anaeróbio e o trabalho total durante o ciclismo, sem efeitos adversos na frequência cardíaca.

**PALAVRAS-CHAVE:** Alimento funcional. Desempenho físico funcional. Exercício.

## Introduction

Food supplements are often used by athletes and recreational sports practitioners to achieve better performance in their practices (Burke, 2008). Caffeine is a commonly used substance with the potential to increase performance in muscular endurance, speed of movement, muscular strength, running, jumping, throwing, and sport-specific aerobic and anaerobic tasks (Guest et al., 2021). However, when consumed in elevated dosages (400 mg/day), caffeine can generate adverse effects, such as impacting sleep and inducing feelings of anxiety (Wikoff et al., 2017). In this context, other components have been gaining prominence for their potential ergogenic effect, such as guarana (*Paullinia cupana*).

Guarana (*Paullinia cupana*) is a native species of the Amazon region in South America. Its composition includes a high concentration and bioavailability of methylxanthines (e.g., caffeine, theophylline and theobromine), flavonoids (e.g., catechins and epicatechins), proanthocyanidins, tannins, and saponins (Hack et al., 2023; Torres et al., 2022). Guarana contains compounds with

stimulant properties (Kennedy et al., 2008), which may elicit physiological responses similar to those induced by caffeine during exercise. Therefore, due to the presence of compounds that act synergistically with caffeine, guarana may produce ergogenic effects comparable to those of caffeine, while potentially reducing the risk of adverse reactions (Kennedy et al., 2008).

Studies investigating the effects of guarana supplementation, either alone or in combination with other compounds, on physical performance have shown heterogeneous results. Overall, most evidence suggests a reduction in perceived exertion (Alkhatib et al., 2015; Veasey et al., 2015; Pomportes et al., 2019), although this finding is not consistently reported across studies (Pomportes et al., 2017). Regarding performance outcomes, cycling peak power output shows inconsistent responses, with some studies reporting improvements and reduced fatigue index (Pomportes et al., 2015), while others found no differences compared to placebo (Pomportes et al., 2017). Physiological parameters such as lactate and maximal oxygen uptake ( $VO_2\text{max}$ ) do not appear to be significantly influenced by supplementation (Pomportes et al., 2019; Gurney et al., 2022), whereas an increase in total work during aerobic exercise has been observed (Penna et al., 2024). In contrast, variables such as vertical jump height and agility remain unchanged (Kaczka et al., 2022). Heart rate (HR) responses have also shown inconsistent findings across studies (Alkhatib et al., 2015; Pomportes et al., 2019). Given these discrepancies in the literature, a systematic synthesis of these outcomes is warranted.

Furthermore, to our knowledge, despite the aforementioned evidence and the existence of systematic reviews on the ergogenic effect of caffeine on exercise performance (Grgic et al., 2020), no systematic reviews with meta-analysis investigating the effects of guarana on exercise performance in healthy adults have been conducted so far. In this context, the reviews conducted by Hack et al. (2023) and de Araujo et al. (2021) addressed the effects of guarana supplementation on cognitive outcomes (e.g., response time) (Hack et al., 2023) and fatigue in cancer patients (de Araujo et al., 2021), respectively. This gap in the literature highlights the relevance of the present systematic review, which may provide valuable insights for nutrition professionals and individuals who frequently consume stimulant foods in their daily lives. Therefore, we aimed to conduct a systematic review with meta-analysis of studies examining the acute effects of guarana supplementation or guarana-containing compounds on physiological responses, perceived exertion, and exercise performance in healthy adults.

## Methods

### Study reporting and protocol registration

The current systematic review with meta-analysis was performed following the recommendations from the Cochrane Collaboration (Higgins et al., 2019) and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting guidelines (Page et al., 2021). The review protocol was registered on PROSPERO under the number CRD42023399300. The study selection, data extraction, and the methodological quality assessment of the included studies were conducted by two independent investigators with disagreements resolved by consensus.

## Data sources and searches

In March 2025, a systematic search was conducted across five electronic databases - ISI Web of Knowledge, MEDLINE/Pubmed, Embase, SportDiscus, and BIREME - without restrictions on time period or language. Furthermore, a list of references from a relevant review (Hack et al., 2023) and included trials were manually searched. Combinations were used with the descriptors and keywords adapted for each database (adult OR athletes) AND (guarana OR "*Paullinia cupana*"). Searches were combined using the terms MeSH or Emtree, and using Boolean operators "AND" and "OR." Full details of the search strategy are presented in the Supplementary Table S2.

## Study selection and screening criteria

The present review was composed of a three-stage screening process, which were conducted by two independent reviewers with disagreements resolved by consensus. Initially, titles were screened and irrelevant papers were excluded (e.g., *in vitro* studies). In the second stage, the reviewers screened studies by abstracts. In the last stage, the full text of each study was assessed according to the eligibility criteria. The following inclusion criteria were adopted: 1) randomized controlled trials; 2) healthy adults (defined as individuals aged between 19 and 44 years according to Medical Subject Headings); 3) guarana supplementation or compound formulations containing added guarana administered during sports practices, aerobic and/or resistance exercise interventions; 4) a control condition with no guarana supplementation or compounds containing guarana during exercise; and 5) assessment of perceived exertion, physiological and/or exercise performance parameters.

Studies that did not meet all the inclusion criteria or met any of the exclusion criteria were excluded from this review. The exclusion criteria comprised the assessment of chronic effects and the unavailability of the full-text article. Only randomized controlled trials, whether using crossover or parallel-group designs, with fully accessible texts were included. The primary outcomes analyzed were the acute effects of guarana supplementation or guarana-containing compounds on physical effort, exercise performance, and physiological parameters. Physical effort was assessed through measures of perceived exertion. Exercise performance was evaluated using indicators such as peak power output, fatigue, speed, strength, total work performed, and vertical jump height. Physiological outcomes included HR, maximal oxygen uptake ( $VO_{2_{max}}$ ), peak oxygen uptake ( $VO_{2_{peak}}$ ), blood glucose levels, and lactate threshold. Additionally, secondary outcomes were considered in the analysis, including the type, volume, and intensity of exercise, as well as the dose and type of guarana supplementation administered.

## Data extraction

Searches on databases were completed by March 2025. The data from each study were extracted individually and exported to a spreadsheet. Study design, sample size, participant characteristics, supplementation specifications, exercise (type, volume, and intensity), measured outcomes (main outcomes and assessments), and results [intervention (guarana or compounds containing guarana) and control (no guarana supplementation) pre-post changes by mean and

standard deviation values] were extracted. Data from both crossover and parallel-group studies were included. When studies did not provide enough data (i.e. incomplete reporting), additional information was requested to the corresponding author of the study by e-mail. When the authors did not respond or did not provide the required data, the mean and standard deviation values were manually extracted from the plots using WebPlotDigitizer. In case of incompatible data (e.g., non-groupable intervention), the study was not included in meta-analysis. In the study by Penna et al. (2024), supplementary data was not accessible, and due to the format of the graph, it was not possible to extract the data using software.

## Data synthesis and statistics

Common outcomes reported in two or more studies were pooled in meta-analyses using the standardized mean difference (SMD), standard error (SE), and 95% confidence interval (95% CI) as measures of effect size, dispersion and precision, respectively. Effect sizes were classified according to Cohen's d values (Higgins et al., 2019), where an SMD of 0.40 was considered a small effect, 0.40–0.70 a moderate effect, and 0.70 a large effect (Cohen, 1988). Accordingly, two meta-analyses were performed to assess the acute effects of guarana supplementation or guarana-containing compounds on perceived exertion and HR during exercise. For all meta-analyses, a random-effects model was used. This model was adopted *a priori* due to the expected heterogeneity in the types of intervention and outcome measures across the studies. Heterogeneity was assessed using the  $I^2$  statistic, which was interpreted according to Higgins et al. (2003), where values above 25% and 50% were classified as moderate and high heterogeneity, respectively. When moderate or high heterogeneity was found ( $I^2 \geq 25\%$ ), sensitivity analyses were performed to explore potential sources of variation. All statistical analyses were performed using Comprehensive Meta-Analysis software (version 3.0; Biostat, Englewood, NJ, United States). The level of statistical significance was set at  $\alpha \leq 0.05$ .

## Studies' quality appraisal

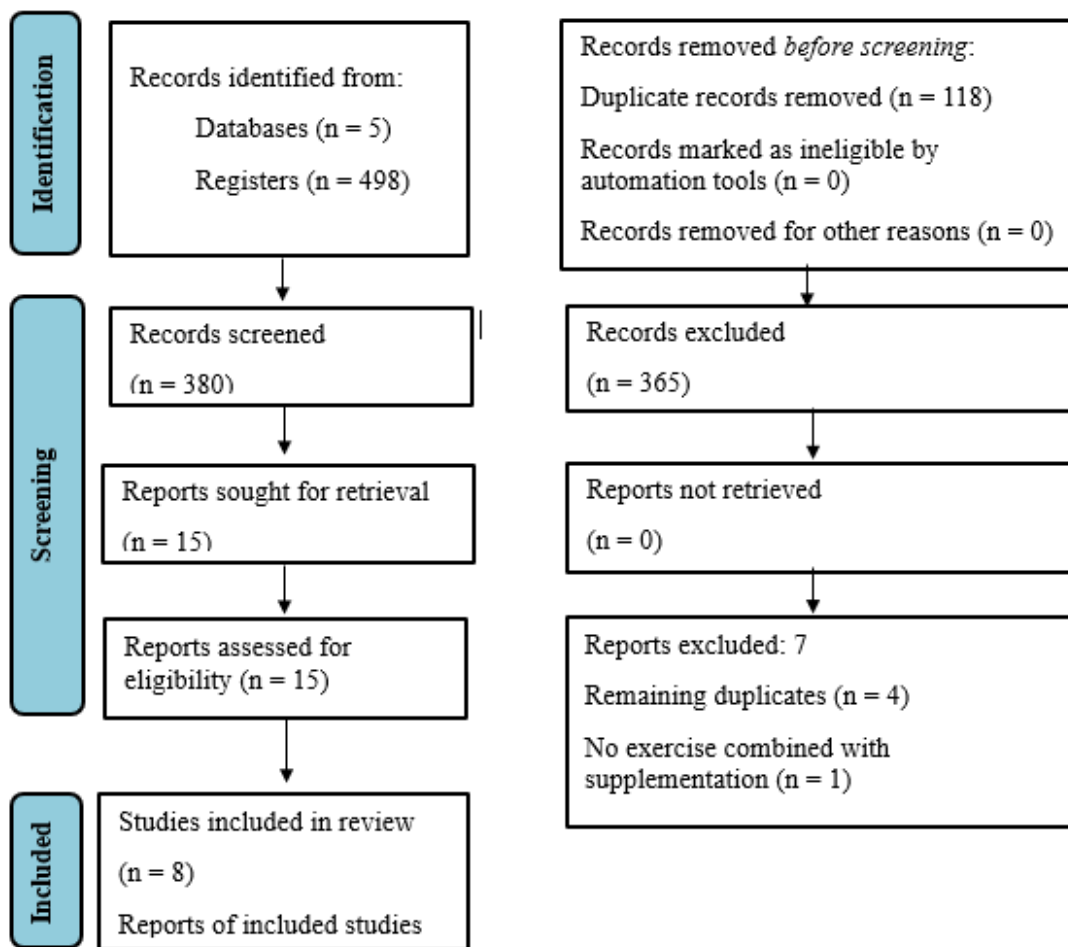
The methodological quality of the included studies was assessed by two independent reviewers, with disagreements resolved by consensus. The Revised Cochrane Risk-of-Bias Tool for Randomized Trials (ROB 2) was used to evaluate the risk of bias in both parallel-group and crossover trials (Sterne et al., 2019). ROB 2 assesses the risk of bias in the estimation of the effect of assignment to the intervention, typically corresponding to an intention-to-treat analysis. The tool comprises five domains: (1) bias arising from the randomization process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in measurement of the outcome; and (5) bias in selection of the reported result. Each domain was rated as “low risk of bias,” “some concerns,” or “high risk of bias.” An overall risk-of-bias judgment was derived for each study outcome. A study was considered to have a low risk of bias if all domains were rated as low risk; “some concerns” if at least one domain raised concerns without any high-risk judgment; and “high risk of bias” if one or more domains were judged to be at high risk, or if multiple domains raised concerns in a way that substantially reduced confidence in the result (Sterne et al., 2019).

## Results and Discussion

### Search results

A flow diagram of the literature search and screening is depicted in Figure 1. The initial search identified 498 studies in all combined databases. After the full-text screening, 15 studies were considered eligible. Of these, eight studies (Alkhatib et al., 2015; Gurney et al., 2023; Kaczka et al., 2022; Penna et al., 2024; Pomportes et al., 2017; Pomportes et al., 2019; Pomportes et al., 2014; Veasey et al., 2015) met all the inclusion criteria and were included in the review. No additional studies were found from other sources.

Figure 1: PRISMA chart of the study flow.



Source: The authors.

## Characteristics of the included studies

Table 1 summarizes the main information from the included studies. All studies were randomized controlled trials ( $n = 8$ ), and all adopted a crossover design. Each study included a control condition (i.e., no guarana supplementation). The samples consisted of healthy individuals (Veasey et al., 2015); healthy physically active individuals (Alkhatib et al., 2015; Gurney et al., 2023; Pomportes et al., 2017); modern pentathlon athletes (Pomportes et al., 2019); high-level fencing and squash athletes (Pomportes et al., 2014); recreational handball players (Kaczka et al., 2022); and cyclists and non-cyclists (Penna et al., 2024). The sample size varied from 10 (Pomportes et al., 2019) to 40 (Veasey et al., 2015) participants per condition. Only one study reported a sample size calculation (Penna et al., 2024). A total of 163 participants: 131 men and 32 women, with a mean age of 22.1 years, were evaluated across all studies.

Table 1: Summary of studies on the acute effects of guarana supplementation or guarana-added compounds versus control (placebo) during exercise.

Study	Design/ intervention	Participants	Exercise protocol	Outcomes
(Alkhatib et al., 2015)	RCT Crossover design 1: Control 2: Intervention: thermogenic (SHRED) 70 mg green tea leaf, 50 mg anhydrous caffeine and 100 mg guarana seed extract)	Healthy and physically active adults. (n = 12; M = 7; W = 5) 24 ± 3.8 years	Ramp exercise cycling protocol (Start at 30 Watts (women) 50 Watts (men) being ramped up at a cadence of 65-70 rpm, exhaustion being considered when the RER 1.1; exceeded the age-predicted maximum HR; or the participant was unable to maintain the cadence for 15s even with verbal encouragement)	Perceived exertion: ↓12.97% HR: n.s.
(Gurney et al., 2023)	RCT Crossover design 1: Control 2: guarana (125 mg/kg)	Healthy and physically active adults. (n = 25; M = 18; W = 7) 21 ± 1 years	Ramp exercise cycling protocol (Gradual increase of 25-40 Watts per minute based on reported level of physical activity of participant; exhaustion being considered when RER 1.1; exceeded age- predicted maximum HR; or VO <sub>2</sub> reached a plateau)	VO <sub>2max</sub> : n.s. Peak power: n.s.
(Kaczka et al., 2022)	RCT Crossover design 1: Control 2: guarana (200 mg caffeine + 200 mg guarana)	Adult recreational handball players (n = 24; M = 24; W = 0) 23.8 ± 1.4 years	Y-Shaped test (agility test) and countermovement jump	Agility: n.s. Vertical jump: n.s.
(Pomportes et al., 2014)	RCT Crossover design 1: Control 2: guarana (1000 mg creatine + 1500 mg guarana)	High-level fencing and squash athletes (n = 17; M = 10; W = 7) 18.2 ± 3.7 years	Six maximal sprints on ergocycle sprints with 6-s long intercepted by 25-s of resting	Peak power: ↑ 2.57% Fatigue index: ↓ 25.30%

(Pomportes et al., 2017)	RCT Crossover design 1: Control 2: guarana mouth rinsing (0.4 g/25 ml guarana)	Healthy and physically active adults. (n = 24; M = 16; W = 8) 26 ± 8 years	40-min cycling exercise (60% PPO)	Perceived exertion: n.s.
(Pomportes et al., 2019)	RCT Crossover design 1: Control 2: guarana (300 mg)	Athletes of the Modern Pentathlon. (n = 10; M = 6; W = 4) 18.6 ± 2 years	40-min treadmill run (RPE 13)	Perceived exertion: ↓12.24% HR: ↓1.35% Lactate threshold: n.s.
(Veasey et al., 2015)	RCT Crossover design 1: Control 2: Multivitamin and mineral complex with guarana (MVM + guarana) (222.2mg)	Healthy and physically active adults. (n = 40; M = 40; W = 0) 21.4 ± 3.0 years	30-min treadmill run (60% VO <sub>2Max</sub> )	Perceived exertion: ↓ 2.7%
(Penna et al., 2024)	RCT Crossover design 1: control 2: Guarana (500 mg)	Cyclists and non-cyclists (a physical activity level greater than 5 hours per week) (n = 11; M = 10; W = 1)	From 60% to 65% of W <sub>max</sub> for cyclists; from 55% to 60% of W <sub>max</sub> for non-cyclists; both alternating intensity every 15 minutes; and the final 15 minutes at a self-selected intensity	RPE: n.s. Lactate: n.s. RER: n.s. Glucose: n.s. VO <sub>2peak</sub> : n.s. Strength: n.s. %HR <sub>peak</sub> : n.s. Total Work: ↑ 4%

n.s. = not significant; RCT = randomized clinical trial; M = man; W = woman; RER = Respiratory Exchange Ratio.

Among the types of exercise, participants performed cycling on a cycle ergometer (n = 5) (Alkhatib et al., 2015; Gurney et al., 2023; Penna et al., 2024; Pomportes et al., 2017; Pomportes et al., 2014), treadmill running (n = 2) (Pomportes et al., 2019; Veasey et al., 2015), and agility and vertical jump tasks (n = 1) (Kaczka et al., 2022).

Regarding supplementation types, Alkhatib et al. (2015) used a commercially available multi-ingredient product (Shred-Matrix®), containing green tea extract, yerba mate, guarana seed extract, anhydrous caffeine, saw palmetto, fo-ti, eleuthero root, cayenne pepper, and yohimbine HCl. Alkhatib et al. (2015) used guarana (100 mg), green tea leaf (70 mg), and caffeine (50 mg); Kaczka et al. (2022) used caffeine (200 mg) plus guarana (200 mg). Guarana alone was used in four studies (n = 4): Penna et al. (2024) (500 mg), Gurney et al. (2023) (125 mg/kg), Pomportes et al. (2019) (300 mg), and Pomportes et al. (2017) (0.4 g/25 mL). One study used a multivitamin with added guarana (222.2 mg) (n = 1) (Pomportes et al., 2014), and another combined creatine (1000 mg) with guarana (1500 mg) (n = 1) (Pomportes et al., 2014). Almost

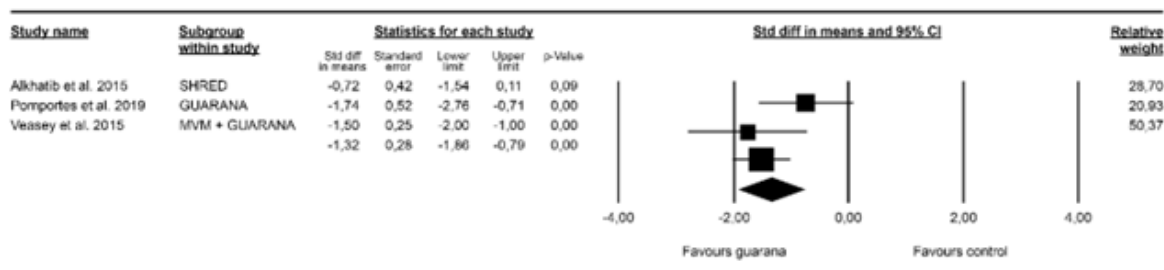
all studies administered the compounds orally in the form of beverages, except for one study that used mouth rinsing (Pomportes et al., 2017). Almost all studies administered the compounds orally, in the form of beverages, except for one study that used mouth rinsing (Pomportes et al., 2017).

The effects of guarana supplementation during exercise were assessed by some studies on perceived exertion ( $n = 5$ ) (Alkhatib et al., 2015; Penna et al., 2024; Pomportes et al., 2017; Pomportes et al., 2019; Veasey et al., 2015), and physiological responses ( $n = 4$ ) (Alkhatib et al., 2015; Gurney et al., 2023; Penna et al., 2024; Pomportes et al., 2019). While others ( $n = 4$ ) have evaluated the effects of guarana supplementation or guarana-containing compounds on physical exercise performance (Gurney et al., 2023; Kaczka et al., 2022; Penna et al., 2024; Pomportes et al., 2014).

### Guarana supplementation effects on perceived exertion

A meta-analysis was performed to estimate the effects for guarana supplementation on perceived exertion ( $n = 3$ ) (Alkhatib et al., 2015; Pomportes et al., 2019; Veasey et al., 2015) (Figure 2). The study by Penna et al. (2024) was not included in the meta-analysis due to the unavailability of data. A large effect was observed for reduced perceived exertion (SMD: -1.32; 95% CI -1.85 to -0.79;  $p = 0.01$ ;  $I^2 = 36\%$ ) with the guarana supplementation in exercise.

Figure 2: Acute effects of guarana supplementation or guarana-added compounds versus control (placebo) on perceived exertion.



#### Meta Analysis

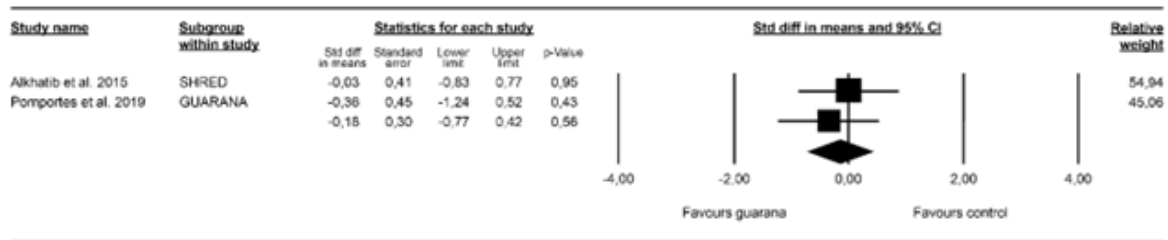
SHRED = multi-ingredient supplement; MVM = vitamin and mineral complex with guarana.

Source: The authors.

### Guarana supplementation effects on physiological parameters

$VO_{2Max}$  responses were investigated in a single study (Gurney et al., 2023), as well as  $VO_{2peak}$ , RER and glucose (Penna et al., 2024). The lactate threshold was assessed in two studies (Penna et al., 2024; Pomportes et al., 2019); however, as previously mentioned, it was not possible to obtain the data from the study by (Penna et al., 2024) to conduct a meta-analysis for this variable. No effect of guarana supplementation was found on any of the aforementioned variables. A meta-analysis was performed to estimate the effects on guarana supplementation on HR ( $n = 2$ ) (Alkhatib et al., 2015; Pomportes et al., 2019) (Figure 3). No effect was observed on HR (SMD: -0.18; 95% CI -0.77 to 0.42;  $p = 0.56$ ;  $I^2 = 0\%$ ) with the guarana supplementation in exercise.

Figure 3: Acute effects of guarana supplementation or guarana-added compounds versus control (placebo) on HR.



#### Meta Analysis

SHRED = multi-ingredient supplement.

Source: The authors.

## Guarana supplementation effects on exercise performance

PPO during cycle ergometer exercise with guarana supplementation was investigated in three studies (Gurney et al., 2023; Penna et al., 2024; Pomportes et al., 2014). Pomportes et al. (2014) assessed PPO across six maximal 6-second ergocycle sprints, each separated by 25 seconds of rest. Gurney et al. (2023) employed a ramp protocol with power increments of 25–40 W per minute, adjusted according to the self-reported physical activity levels of the participants. Penna et al. (2024) evaluated physiological, psychological, and performance variables during a test performed at 60% to 65% of  $W_{max}$  for cyclists and 55% to 60% of  $W_{max}$  for non-cyclists, with intensity alternating every 15 minutes, and the final 15 minutes performed at a self-selected intensity. Guarana supplementation combined with creatine led to increased PPO in anaerobic exercise (2.57%) (Pomportes et al., 2014), while in aerobic exercise, improvements were observed only in total work (4%) (Gurney et al., 2023). Pomportes et al. (2014) also examined the effect of guarana with creatine on the fatigue index across sprints, reporting a reduction in fatigue (-25.30%). Finally, Kaczka et al. (2022) assessed the effects of caffeine combined with guarana on performance in vertical jump and agility tasks, finding no significant differences compared to the control condition.

## Summary of Key Findings and Discussion

To the best of our knowledge, this study presents the first synthesis of available evidence on the acute effects of guarana supplementation or compounds with added guarana during exercise on the perceived exertion, physiological responses and exercise performance exclusively in healthy adults of different/diverse training status. We found that guarana supplementation during exercise decreases both perceived exertion and fatigue index, increases PPO in anaerobic exercise and total work in cycling, and produces no adverse effects on HR.

Guarana contains significant levels of caffeine (approximately 6%) (Schimpl et al., 2013), which probably accounts for most of the biological effects of guarana. Caffeine has been described as an antagonist of adenosine receptors, which may also modulate rapid movement across the blood-brain barrier, which consequently increases dopamine concentrations in the brain (Pomportes et al., 2017). This results in heightened alertness, vigilance, attention and

reaction time (McLellan et al., 2016), as well as reduction in perceived exertion (Mielgo-Ayuso et al., 2019). In addition, guarana also has components possibly synergistic to caffeine, such as tannins, saponins, and flavonoids (e.g., catechins and epicatechins), and other methylxanthines (e.g., theobromine and theophylline), which may potentiate the aforementioned effects (Galduróz & Carlini Ede, 1994; Haskell et al., 2007; Kennedy et al., 2004; Pomportes et al., 2014; Schimpl et al., 2013). These possible mechanisms may explain the decreased perceived exertion found in our meta-analysis (Figure 2).

Similar to the effects of caffeine consumption alone (Glaister & Gissane, 2018), our meta-analysis showed that guarana supplementation does not affect HR during submaximal exercise (Figure 3). Interestingly, previous research has shown that adenosine infusion tends to elevate resting HR by reducing parasympathetic activity and enhancing sympathetic nervous system outflow (Rongen et al., 1999). Therefore, the inhibitory effect of caffeine—present in guarana—on adenosine receptors may account for the lack of change in HR during submaximal exercise. Consequently, the HR variations observed in some studies may be more likely due to increased exercise intensity rather than the effects of caffeine itself (Glaister et al., 2016). Furthermore, as indicated by our meta-analysis (Figure 3), other bioactive components in guarana that act synergistically with caffeine also appear to have no effect on HR.

Guarana supplementation also appears to produce no changes on  $VO_{2Max}$ ,  $VO_{2peak}$ , RER, glucose and lactate threshold compared to caffeine supplementation and placebo in physically active adults (Gurney et al., 2023; Penna et al., 2024; Pomportes et al., 2019). A meta-regression by Southward et al. (2018) also found no effect of caffeine on  $VO_{2Max}$ . The authors attribute the variability of the results found primarily to the genetics of the participants, as the CYP1A2 and ADORA2A genes significantly contribute to caffeine metabolism and sensitivity, respectively. CYP1A2 is a member of the cytochrome P450 enzyme family, which as a group is responsible for metabolizing approximately 75% of all drugs. Specifically, CYP1A2 plays a major role in caffeine metabolism, converting it primarily into paraxanthine, and to a lesser extent into theobromine and theophylline (Guengerich, 2008). Changes in the rate of caffeine metabolism have been associated with an A → C polymorphism of CYP1A2. Carriers of the homozygous A/A allele have been found to metabolize caffeine faster than carriers of the C allele, such as A/C and C/C genotypes. In addition, carriers of the homozygous C/C allele metabolize caffeine more slowly (Djordjevic et al., 2008; Ghotbi et al., 2007; Sachse et al., 1999). Thus, carriers of the A/C and C/C genotypes may exhibit a longer half-life of caffeine, thereby extending its ergogenic effect (Southward et al., 2018).

However, the time between supplement ingestion and the end of exercise is likely insufficient for individuals with this polymorphism to experience any performance impairment. The half-life of caffeine ranges from 2.5 to 4.5 hours (Viani, 1988). An analysis of the protocols included in the meta-regression by Southward et al. (2018) indicates that most do not extend beyond the minimum duration required to reach caffeine's half-life. This limitation may introduce confounding effects and reveal a potential bias in the interpretation of results based on genetic variability. Moreover, in the studies conducted by Pomportes et al. (2019) and Gurney et al. (2023), the time between guarana ingestion and the end of exercise did not exceed 90 minutes. Therefore, the influence of genetic polymorphisms related to caffeine metabolism may be more relevant in prolonged aerobic exercise lasting over 150 minutes following supplementation. It is

also important to note that peak plasma concentrations of caffeine typically occur between 15 and 120 minutes after ingestion (Arnaud, 1987). This time window overlaps with the exercise duration in most of the evaluated protocols (Gurney et al., 2023; Pomportes et al., 2019; Southward et al., 2018), which may have implications for the timing and magnitude of ergogenic effects. Furthermore, other bioactive compounds found in guarana that act synergistically with caffeine also failed to produce significant effects on  $VO_2$ Max,  $VO_2$ peak, glucose levels, or lactate threshold (Gurney et al., 2023; Penna et al., 2024; Pomportes et al., 2019).

The studies included in this review present contradictory findings regarding exercise performance outcomes. In anaerobic exercise, higher peak power output (PPO) and a lower fatigue index were observed during repeated sprints on a cycle ergometer (Pomportes et al., 2014). However, no significant differences were reported in countermovement jump performance or the Y-shaped agility test (Kaczka et al., 2022). In aerobic exercise, such as on the cycle ergometer, no differences in muscular strength were found compared to the control group; nonetheless, a 4 percent increase in total work was reported (Penna et al., 2024). When examining the supplementation protocols used in these studies, Pomportes et al. (2014) administered guarana in combination with creatine. In addition to the known effects of guarana, creatine has well-documented ergogenic benefits in high-intensity, short-duration exercise. Creatine supplementation increases the intracellular phosphocreatine pool, thereby enhancing the muscle cell's ability to resynthesize adenosine triphosphate (ATP) (Wax et al., 2021). This potential synergistic effect between guarana and creatine may explain the improved performance outcomes reported by Pomportes et al. (2014). It is also important to note that the studies by Pomportes et al. (2014) and Penna et al. (2024) used the highest doses of guarana among those included in this review—1,500 mg and 500 mg, respectively—which may account for the fact that these were the only studies to report improvements in performance-related variables.

While Kaczka et al. (2022) used a combination of guarana and caffeine, both compounds share, at least in part, a similar mechanism of action—namely, antagonism of adenosine receptors. Given that guarana contains a high concentration of caffeine, the ingestion of caffeine alone may not produce a greater effect compared to guarana supplementation alone. Moreover, agility tests such as the Y-shaped test require a well-developed technical skill set, which may contribute to increased intra-subject variability and, consequently, a lack of observable differences in performance outcomes (Altmann et al., 2019). Finally, the findings of Gurney et al. (2023) may have been influenced by several of the mechanisms discussed above, including interindividual genetic variability and differences in the timing of peak plasma caffeine concentration (Arnaud, 1987; Southward et al., 2018), which may help explain the absence of performance improvements in their study.

## Limitations

Although our study provides an overview of the scientific literature on the effects of guarana supplementation on exercise performance in apparently healthy individuals and offers directions for future research, several limitations must be acknowledged. First, the findings cannot be generalized to other populations, such as individuals with clinical conditions, children, adolescents, or older adults. Additionally, the relatively small number of included studies limits the robustness of the conclusions and precluded the assessment of publication

bias. Methodological concerns should also be considered, as most studies ( $n = 7$ ) did not report sample size calculations, increasing the risk of type I error. Furthermore, there is substantial heterogeneity among the included studies regarding supplementation protocols (e.g., dosage, timing of intake prior to exercise, and use of guarana alone or in combination with other compounds), as well as exercise modalities and intensity. This variability limits comparability across studies and hinders the establishment of clear, evidence-based recommendations.

## Practical applications

From a practical perspective, it is currently not possible to provide precise guidance on guarana supplementation for exercise performance. There is no established consensus on an appropriate dose of guarana administered alone and normalized by body mass. However, based on the pharmacokinetics of caffeine derived from guarana, ingestion between 15 and 120 minutes prior to exercise may represent a potentially effective window, as this corresponds to the typical peak plasma concentration period (Arnaud, 1987). Overall, further high-quality studies with rigorous methodological designs are needed to better elucidate both the acute and chronic effects of guarana supplementation on aerobic and anaerobic exercise performance.

## Conclusion

Based on the current evidence, guarana supplementation or compounds containing guarana may reduce perceived exertion (with a large effect size), decrease fatigue index, and enhance peak power output in anaerobic exercise, as well as total work during cycling. No adverse effects were observed on HR, and no significant effects were detected on  $VO_2\text{Max}$ ,  $VO_2\text{peak}$ , glucose, respiratory exchange ratio, or lactate threshold. However, due to the limited number of high-quality studies, the variability in supplementation protocols, and the frequent use of guarana in combination with other bioactive substances, these findings should be interpreted with caution. Further randomized controlled trials using guarana alone, with standardized doses and well-defined exercise protocols, are needed to confirm these results and explore additional outcomes, such as oxidative stress and inflammatory markers, in both aerobic and anaerobic exercise contexts.

## Declaration of interest statement

The authors declare no conflict of interest.

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