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Effects of dietary supplements on athletic performance in elite soccer players: a systematic review

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ABSTRACT

Dietary supplements are widely used among athletes, and soccer players are no exception. Nevertheless, evidence supporting the use of dietary supplements aiming to enhance performance in soccer is somewhat contradictory, scarce, or even nonexistent. Thus, the present study aimed to systematically review and synthesize the effects of dietary supplements on athletic performance (e.g. distance covered, sprinting, jump performance) in elite soccer players. Studies enrolling highly trained, elite, and world-class soccer players using dietary supplements were searched in MEDLINE/PubMed, Web of Science, Scopus, and EBSCO databases in June 2022. In total, 1043 studies were identified, and 18 met the eligibility criteria. The studies evaluated the impacts on athletic performance of several dietary supplements, including caffeine, creatine, protein, beverages with carbohydrates and electrolytes, tart cherry juice, nitrate-rich beetroot juice, sodium bicarbonate with minerals, yohimbine, and a proprietary nutraceutical blend. Caffeine supplementation in doses between 3 and 6 mg/kg of body mass may improve jump height and sprint ability, particularly in female players, but individual response to caffeine must be considered. Creatine may improve sprint, agility, and in female players, jump performance. Protein supplementation can improve sprint and jump performance between matches, especially if protein ingested from food is not up to recommendations. Beverages containing carbohydrates and electrolytes can be used as part of the strategies to achieve carbohydrate intake during training and match-days but used alone do not benefit athletic performance. Tart cherry juice might be useful for maintaining athletic performance after matches that produce higher force loss and exercise-induced muscle damage, although polyphenols from the diet might attenuate the effects of tart cherry supplementation. Nitrate-rich beetroot concentrate can attenuate performance decrease in

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the days following matches. Further investigation with sodium bicarbonate alone is necessary, as supplementation protocols with elite players included other substances. Finally, the available data does not support yohimbine supplementation or the use of Resurgex Plus® to improve athletic performance in elite soccer players. Still, more well-designed research with elite soccer players is needed to improve support and advice regarding the use of dietary supplements for athletic performance enhancement.

1. Introduction

Dietary supplements may be defined as "a food, food component, nutrient, or non-food compound that is purposefully ingested in addition to the habitually consumed diet with the aim of achieving a specific health and/or performance benefit," as recently proposed by the International Olympic Committee (IOC) consensus statement [1]. They are used for several purposes, such as to improve athletic or cognitive performance, accelerate recovery from intense physical efforts, or prevent nutritional deficiencies [1]. In soccer, dietary supplements are frequently a part of nutritional strategies to support players in improving performance and recovery [2]. Available data suggest that 47.8% to 93.7% of soccer players report using dietary supplements [3–5], for health maintenance and performance [3,6]. Caffeine, creatine, protein, omega-3 fatty acids, and vitamin D supplements have been reported to be the most commonly used dietary supplements by elite soccer players [4,6].

Evidence regarding the benefits of dietary supplements is a matter of interest to support teams working with elite soccer players (e.g. nutritionists, physicians, and sports scientists). Understanding if dietary supplements are ergogenic and how they should be used, depending on individual goals and requirements, is key to the success of nutritional interventions. Although potentially useful, dietary supplements may not be harmless and are not exempt from risks, such as the presence of banned substances. Furthermore, with a growing number of studies assessing dietary supplements utility for performance purposes, it is necessary to understand in which conditions dietary supplements can be useful or not, and if benefits are observed equally among all players. Some authors suggest that elite players may respond to supplementation differently when compared to amateurs, and differences in the methodology of each study may lead to misleading results [7]. For example, a recent systematic review and meta-analysis of nitrate supplementation revealed no ergogenic effect in well-trained endurance athletes, although performance benefits were observed in recreationally active, young, healthy men [8]. Another important aspect has to do with the differences observed among elite and amateur players; elite players have better physical performance indicators than amateur players [9], meaning that some dietary supplements when used among amateur athletes may improve their athletic performance while with elite players may be useful to maintain performance. Additionally, given that elite players are often under-congested fixtures (i.e. they are required to play several matches within a short span of time), the use of dietary supplements may be one possible strategy to avoid a decline in physical performance. Indeed, literature about the use of dietary supplements within elite soccer players is still scarce. The fact that elite soccer players often cope with very competitive and congested calendars may reduce their willingness to participate in research work, and this might be the reason for most studies being conducted with recreational or trained players, or athletes from other sports.

Therefore, the present systematic review aimed to provide a comprehensive overview of the effects of dietary supplements on the athletic performance of highly trained, elite, and world-class adult soccer players.

2. Methods

The present systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [10]. Given the scope of the systematic review, the PERSiST (implementing Prisma in Exercise, Rehabilitation, Sports medicine, and SporTs science) guidance [11] was also adopted. The protocol was prospectively registered at the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY 202,260,088).

2.1. Search strategy

Studies enrolling soccer players in interventions using dietary supplements were searched in MEDLINE/PubMed, Web of Science, Scopus, and EBSCO databases between June 20th and 24th, 2022. The search used both specific Medical Subject Headings (MeSH terms) and keywords in natural language: supplement* AND (diet* OR nutr*) AND (soccer OR football) AND (performance OR exercis* OR fitness OR capacit*). There was no limit on the dates of publication. A further search was performed by scanning the reference lists of included articles and reviews [12–20], to reduce the risk of missing relevant articles.

2.2. Eligibility criteria

The PRISMA 2020 guidelines [10] were used to ensure the integrity of the present systematic review. The PICOS model was used to determine the inclusion criteria – *P(population)*: adult (≥18 years old) male and female highly trained/national level soccer players (i.e. competing in national and/or state league or tournaments), elite/international level soccer players (i.e. competing at international level), and world-class soccer players [21]; *I(intervention)*: use of one or more dietary supplements for athletic performance; *C(comparison)*: same conditions with placebo or without dietary supplements; *O(outcome)*: athletic performance outcomes (namely, sprint time, jump height, distance covered, number of sprints, speed, power, and strength); *S(study design)*: randomized controlled trials, crossover or parallel intervention, blind or double-blind.

All peer-reviewed articles in English, published online, were considered, regardless of the publication status. Reviews, commentaries, editorials, letters and meeting abstracts were excluded. Articles were also excluded if the participants were not all players classified as tier 3, 4 or 5 in a recently established framework for athletes [21] (e.g. mixed samples including elite and non-elite players were excluded); not all participants were aged 18 years old or older; no athletic performance outcomes were assessed; and full-text was not available in English. Articles exclusively with rugby, American football, Australian football, or Gaelic football players were not included.

2.3. Study selection

Two authors (R.A. and C.B.O.) independently performed the search and all identified records exported from the databases were imported to EndNote 20.3 (Clarivate Analytics, Philadelphia, USA). Duplicate records were identified using the "Find duplicates" function of EndNote and manually removed after manual check by R. A. and C.B.O. Screening of title and abstract was conducted separately by R.A. and C. B.O., and in case of uncertainty, the full-text article was checked for verification. Disagreement regarding inclusion was discussed with J.C. and J.B. Overall, 116 articles were selected for full-text download and archive, but 3 articles were excluded since, according to information available in Scopus, full-texts were available only in other languages (Persian, Chinese, and Italian). Another study was excluded because of language after a full-text review. Among the included studies, the authors of two articles [22,23] were contacted for further information about population characteristics.

2.4. Data extraction

Data on population (i.e. number of players, competitive level, sex, and age), country of origin, supplementation protocol (i.e. substance or nutrient, dose, and duration), exercise test, and athletic performance outcomes were extracted from the included studies by one author (R.A.) and subsequently reviewed by another author (C.B.O.).

2.5. Risk of bias

Independently, two authors (R.A. and C.B.O.) judged the risk of bias of the included studies using the Cochrane Risk of Bias (RoB) Tool V.2. [24], encompassing five domains: bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported results. Each potential source of bias was graded as low risk of bias, some concerns, and high risk of bias. Disagreements were settled by consensus among authors or through consultation with a third reviewer (J.B.).

3. Results

3.1. Study selection and study characteristics

The database search identified 1043 records. After removing the duplicates, titles and abstracts were screened, and 572 records were excluded. The full text of the 113 reports was assessed for eligibility. The main reasons leading to exclusion after full-text screening were as follows: competitive level of participants ($n = 32$); participants were not soccer players ($n = 30$); participants were young players aged under 18 years ($n = 20$); no athletic performance outcomes were assessed ($n = 18$). Additionally, 24 records were identified

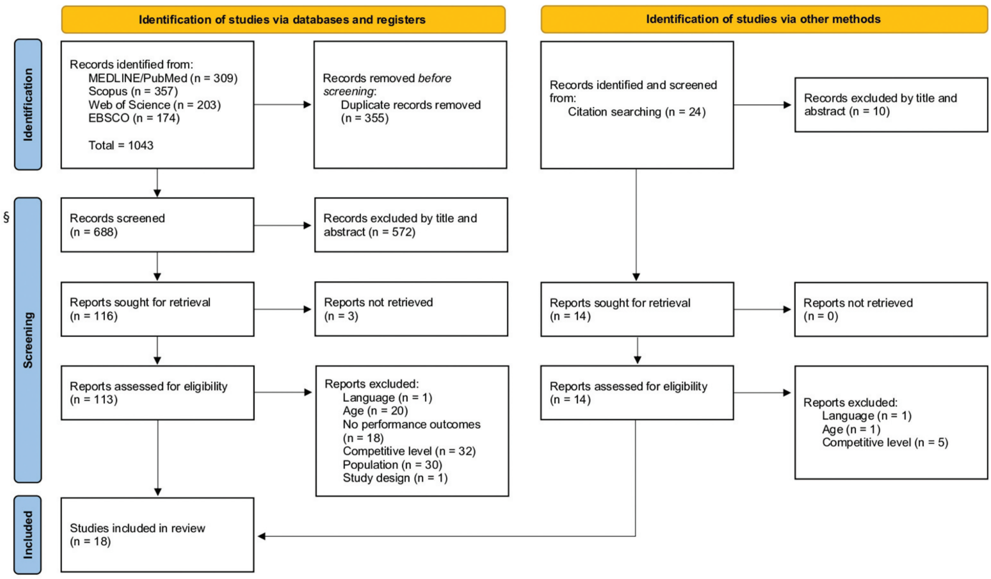

Figure 1. PRISMA Flow Diagram.

from citation searches. In total, 18 studies, all of them randomized placebo-controlled trials, involving a total sample of 307 adult highly trained and elite soccer players (244 men and 63 women), published from 2000 to 2021, met the inclusion criteria and were extracted for qualitative analysis. Study identification, screening and selection proccess using the PRISMA flow diagram is illustrated in Figure 1.

Caffeine was the most frequent dietary supplement investigated in the included studies, either in the form of beverages [25–28], capsule [22] or chewing gum [29]. Four studies assessed creatine supplementation, isolated in different forms (monohydrate [30,31] and magnesium chelate [32]) or in combination with sodium bicarbonate [33]. Two studies investigated protein supplements (whey vs. soy protein [34] and milk protein vs. placebo [35]). The remaining studies investigated beverages with carbohydrates and electrolytes [36,37], tart cherry juice, beetroot juice [38], a supplementation protocol with sodium bicarbonate and minerals [23], yohimbine [39], and Resurgex Plus® (a proprietary blend of nutrients) [40]. Supplementation protocols ranged from one day to five weeks, and are summarized in Table 1.

To assess athletic performance, included studies followed several exercise protocols and measured different outcomes. The most frequent outcomes reported were jump height, distance covered, speed, and sprint time. Exercise tests performed in each study and measured outcomes are also described in Table 1.

3.2. Risk of bias

The RoB 2 assessment tool was used to assess the risk of bias, and an overview of the outcomes can be found in Figure 2. The overall bias across all parallel group randomized trials ($n = 8$) raised some concerns (Figure 2A). Selection of the reported results,

Table 1. Summary of the included studies.

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration)	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Caffeine							
Astorino et al. (2012)	15 females, collegiate players (NAIA soccer team) (19.5 ± 1.1 years)	U.S.A.	Randomised, blind, placebo-controlled, crossover	**Red Bull®** (80 mg caffeine, 1.3 mg/kg +1 g taurine +27 g carbohydrates; 255 mL) vs Canada Dry® Ginger ale (190 mL) mixed with one package of lemon-flavored Crystal Light, **1 h before exercise**	Agility t-test (mean sprint time, sec)	Red Bull® did not alter repeated sprint performance.	Some concerns
Bassini et al. (2013)	19 professional males, major soccer league team affiliated with the Brazilian Soccer Confederation (26.0 ± 1.6 years)	Brazil	Randomized, double-blind, placebo-controlled	**Caffeine** (5 mg/kg) vs lactose (1 g), **1 h before exercise**	Yo-Yo IR2 (velocity, km/h; distance, m)	Caffeine supplementation did not affect the Yo-Yo IR2 performance.	Some concerns
Del Coso et al. (2012)	19 semiprofessional males, soccer team (21 ± 2 years)	Spain	Randomised, double-blind, placebo-controlled, crossover	**Caffeine-containing energy drink** (630 ± 52 mL; volume individually set to 3 mg caffeine/100 mL) – sugar-free Red Bull® vs sugar-free decaffeinated Pepsi® (same volume), **ingested 1 h before exercise**	CMJ (height, cm; power output, kW), RSA (7 × 30 m) (average peak speed and maximal speed, km/h), simulated soccer game (2 × 40 min) (total distance covered, m; distance covered at different speeds, m; number of sprint bouts)	The caffeine-containing energy drink enhanced jump height, increased the ability to repeatedly sprint and the distance covered at high intensity during a simulated soccer game.	Some concerns
Guerra Jr et al. (2018)	12 professional males, soccer team (23.83 ± 5.06 years)	Brazil	Randomised, double-blind, placebo-controlled, crossover	**Caffeine** (5 mg/kg) diluted in 250 mL of artificially sweetened water vs 250 mL of artificially sweetened water, **1 h before exercise**	CMJ (height, cm)	Acute plyometric and sled towing stimuli enhances jump performance, and this is augmented by caffeine ingestion.	Some concerns

(*Continued*)

Table 1. (Continued).

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration)	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Lara et al. (2014)	18 females, soccer team (21 ± 2 years)	Spain	Randomized, double-blind, placebo-controlled, crossover	**Energy drink** [caffeine (3 mg/kg), taurine (18.7 mg/kg), sodium bicarbonate (4.7 mg/kg), and L-carnitine (1.9 mg/kg)] vs identical drink with no caffeine, **ingested 1 h before exercise**	CMJ (height, cm; peak power, W/kg), RSA (7 × 30 m) (average peak speed and maximal speed, km/h), and simulated soccer game (2 × 40 min) (total distance covered, m; distance covered at different speeds, m; number of sprint bouts; maximal speed, km/h)	Ingesting caffeine in the form of an energy drink enhanced jump height, the ability to perform repeated sprints, the total distance covered, and the distance covered at high intensity and sprint velocity during a simulated game.	Some concerns
Ranchordas et al. (2018)	10 university-standard males (19 ± 1 years)	U.K.	Randomised, double-blind, placebo-controlled, crossover	Two pieces of gum containing **caffeine** (100 mg/piece; 2.7 ± 0.2 mg/kg with two pieces) and carbohydrates (2 g/piece) vs gum void of caffeine, chew for **5 min immediately after the warm-up**	CMJ (height, cm), 20 m sprint (time, sec), and Yo-Yo IR1 (distance covered, m)	Chewing the caffeinated gums increased jump height by 2.2% and enhanced performance on the Yo-Yo IR1 by 2%, but the effects were small. No effects on 20 m sprint performance.	Some concerns
Creatine							
Kim et al. (2021)	20 well-trained elite males, soccer team (20.70 ± 1.08 years)	Korea	Randomised, placebo-controlled	**Creatine monohydrate** (5 g, 4×/d) and **sodium bicarbonate** (0.075 g/kg, 4×/d) vs maltodextrin (same dosage), **7 days**	10 m sprint (time, sec), 30 m sprint (time, sec), coordination test (time, sec), arrowhead agility test (time, sec), Yo-Yo IR1 (distance covered, m)	Creatine monohydrate and sodium bicarbonate supplementation improved 30 m sprint performance and agility.	Some concerns
Mujika et al. (2000)	17 highly trained males; soccer team competing at a national level (20.3 ± 1.4 years)	Spain	Randomised, double-blind, placebo-controlled	**Creatine monohydrate** (5 g, 4×/d) vs maltodextrin (same dosage), **6 days**	CMJ (height, cm), RST [6 × 5 m and 6 × 15 m sprint test (time, sec)], IET (distance covered, m), Recovery CMJ (% of the performance attained in the resting CMJ)	Acute creatine supplementation favorably affected RST performance and a limited the decay in jumping ability after the IET.	Some concerns

(*Continued*)

Table 1. (Continued).

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration)	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Ramírez-Campillo et al. (2016)	30 females (22.9 ± 2.5 years)	Chile	Randomised, three-trial, double-blind, placebo-controlled	Phase 1: **Creatine monohydrate** (5 g, 4×/d) vs glucose (same dosage), **1 week** Phase 2: **Creatine monohydrate** (5 g/d) vs glucose (same dosage), **5 weeks**	Day 1: SJ (height, cm), CMJ (height, cm), 20 m sprint (time, sec), RAST [6 × 35 m maximal sprints (time, sec)]; Day 2: 20 cm and 40 cm drop jump reactive strength index (speed, mm/ms), peak jump power (W), peak jump power load (W); Day 3: unilateral 20 cm drop jump reactive strength index (right and left leg) (speed, mm/ms), change-of-direction speed test (i.e. *Illinois* test) (time, s), 20 m multistage shuttle run test (time, min)	Creatine supplementation enhanced jump performance variables and RAST results.	Some concerns
Zajac et al. (2020)	16 well-trained elite males (25.6 ± 3.7 years)	Poland	Randomised, placebo-controlled	**Magnesium creatine chelate** (1375 mg, 4×/d; 0.07 g/kg/d) vs corn starch, **16 weeks**	RAST [TT (s), First 35-m sprint (time, s), Sixth 35-m sprint (time, s), MP (W), AP (W)]	The long-term low dose of magnesium creatine chelate supplementation improved RAST performance.	Some concerns
Protein							
Kritikos et al. (2021)	10 well-trained males (21 ± 1.5 years)	Greece	Randomised, three-trial, double-blind, placebo-controlled, crossover	**Whey protein isolate** or **soy protein isolate** drink (the protein content in each drink was individually adjusted to account for a total intake of 1.5 g/kg/d) vs energy-matched drink (maltodextrin; total protein intake of 0.8–1.0 g/kg/d), **10 days**	MVIC (Nm), concentric and eccentric isokinetic peak torque of the KE and KF of the dominant and non-dominant limb (Nm), CMJ (height, cm), 10 m sprint (time, sec), 30 m sprint (time, sec), RSA fatigue index (%)	Increasing daily protein intake to 1.5 g/kg through ingestion of either whey or soy protein supplements mitigates field performance deterioration during successive speed-endurance training sessions.	Low

(*Continued*)

Table 1. (Continued).

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration)	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Poulios et al. (2018)	20 competitive males (20.6 ± 1.1 years)	Greece	Randomised, double-blind, placebo-controlled, crossover	Match days: **milk protein concentrate** drink [1.15 g/kg/d (80% casein and 20% whey)] vs energy-matched drink (1.37 g/kg/d of maltodextrin), consumed as doses (**immediately after the game, 3 h after, and 6 h after**) Training days: **milk protein concentrate** drink [0.26 g/kg/d of protein (80% casein and 20% whey)] vs energy-matched drink (0.31 g/kg/d of maltodextrin)	10 m sprint (time, sec), 30 m sprint (time, sec), CMJ (height, cm), concentric strength of the KE of the dominant and non-dominant limb (Nm/kg), eccentric strength of the KF of the dominant and non-dominant limb (Nm/kg)	Protein supplementation may improve football locomotor activity during game 2 and seems to prevent a decline of KE and KF peak torque during recovery.	Low
Carbohydrate and Electrolyte drinks							
Abbey et al. (2009)	10 highly trained competitive males (22.5 ± 3.3 years)	U.S.A.	Randomised, blind, three-trial, placebo-controlled, crossover	Clover **honey** mixed with lemonade-flavored drink sweetened with NutraSweet +110 mg sodium/240 mL fluid [6% carbohydrates, 0.5 g/kg; 8.8 mL fluid/kg)] vs **commercially available sports drink** (Gatorade) (6% carbohydrates, 0.5 g/kg) vs lemonade-flavored drink sweetened with NutraSweet, taken **30 min before exercise** and at the **10-min half-time**	Soccer-simulation test [high-intensity run (5 sets), agility drill test (time, sec), ball-shooting drill test, and PSR test to exhaustion]	Acute ingestion of honey and a carbohydrate sports drink before and during the halftime of a soccer-simulation test did not improve performance.	Some concerns

(*Continued*)

Table 1. (Continued).

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Tart Cherry							
Abbott et al. (2019)	10 professional males, reserve team of an English Premier League Club (19 ± 1 years)	U.K.	Randomised, double-blind, placebo-controlled, crossover	**Tart cherry juice** concentrate [22 g carbohydrates; 30 mL (equivalent to 100 sour cherries), 2×/d] mixed with water vs isocaloric cherry-flavored drink (22 g sucrose), **before and after a 90-min match, and 12 h and 36 h after the match**	CMJ (height, cm) and RSI [jump height (cm)/contact time (sec)]	Tart cherry juice did not hasten recovery after a soccer match.	Some concerns
Beetroot Juice							
Daab et al. (2021)	13 males, semiprofessional Tunisian senior squad (22.12 ± 0.56 years)	Tunisia	Randomised, double-blind, placebo-controlled, crossover	**Nitrate-rich beetroot juice** (150 mL, 2×/d; 500 mg nitrates/d), **7 days**	LIST [SJ (height, cm), CMJ (height, cm), MVC of knee extension (N), 20 m sprint (time, sec)]	Chronic beetroot juice supplementation may maintain better performance during the recovery period.	Some concerns
Sodium Bicarbonate (combined with other minerals)							
Chycki et al. (2018)	26 well-trained males, elite Polish league	Poland	Randomised, placebo-controlled	**Sodium bicarbonate** (3000 mg), **potassium bicarbonate** (3000 mg), **calcium phosphate** (600 mg) + **calcium citrate** (400 mg), **potassium citrate** (1000 mg), **magnesium citrate** (1000 mg), 2×/d vs corn starch; **9 days**	RAST [6 × 30 m running test (time, sec)]	Chronic supplementation with sodium and potassium bicarbonate fortified with calcium phosphate, calcium citrate, potassium citrate, and magnesium citrate increased RAST performance.	Some concerns
Yohimbine							
Ostojic (2006)	20 top-level males, First Professional League of Serbia & Montenegro (EXP: 24.3 ± 3.2 years; CON: 23.8 ± 2.9 years)	Servia	Randomised, double-blind, placebo-controlled	**Yohimbine** (10 mg, 2×/d) vs cellulose, **21 days**	Bench press test (repetitions, n), leg press test (repetitions, n), vertical jump test (height, cm), dribble test (time, sec), sprint-power test (time, sec), endurance shuttle-run test (time, sec)	Yohimbine supplementation did not produced marked changes in general or sport-specific exercise performance indicators.	Some concerns

(*Continued*)

Table 1. (Continued).

Author	Population (age, sex, and level)	Region	Study design	Supplementation protocol (substance or nutrient, dose, and duration	Exercise test and outcomes measured	Synthesis of main findings	Overall bias
Resurgex Plus®							
Arent et al. (2010)	22 fit males, Division I college soccer team (EXP: 19.5 ± 0.4 years; CON: 19.4 ± 0.4 years)	U.S.A.	Randomised, blind, placebo-controlled	**Resurgex Plus®** [(75 mg CoQ10, 500 U SOD/Gliadin, 1750 mg ornithine ketoglutarate, 300 mg L-Carnitine, 100 mg nucleotides, 750 mg d-ribose, 500 mg L-glutamine, 100 mg beta-glucans, 12.5 mg fruit polyphenols, and 1750 mg BCAA), 2×/d] vs isocaloric equivalent without Resurgex Plus®; **20 days**	Graded maximal treadmill test to exhaustion [V_{LT} (km/h), TTE (min)]	Preseason training resulted in significant improvements in V_{LT}, and TTE. Supplementing with Resurgex Plus® may enhance some of these effects; however, none reached statistical significance.	Some concerns

Data are presented as mean ± SD or mean ± SEM. AP: Average Power; BCAA: Branched Chain Amino Acids; CMJ: Countermovement Jump; CON: Control Group; EXP: Experimental Group; IET: Intermittent Endurance Test; KE: Knee Extensors; KF: Knee Flexors; LIST: Loughborough Intermittent Shuttle Test; MP: Max Power; MVC: Maximal Voluntary Contraction; MVIC: Maximal Voluntary Isometric Contraction; PSR: Progressive Shuttle-Run; RAST: Running-based Anaerobic Sprint Test; RSI: Reactive Strength Index; RST: Repeated Sprint Test; SJ: Squat Jump; TT: Total Time; TTE: Time to Exhaustion; VLT: Velocity at Lactate Threshold; VO2max: Maximal Oxygen Consumption; Yo-Yo IR1: Yo-Yo Intermittent Recovery Level 1; Yo-Yo IR2: Yo-Yo Intermittent Recovery Level 2.

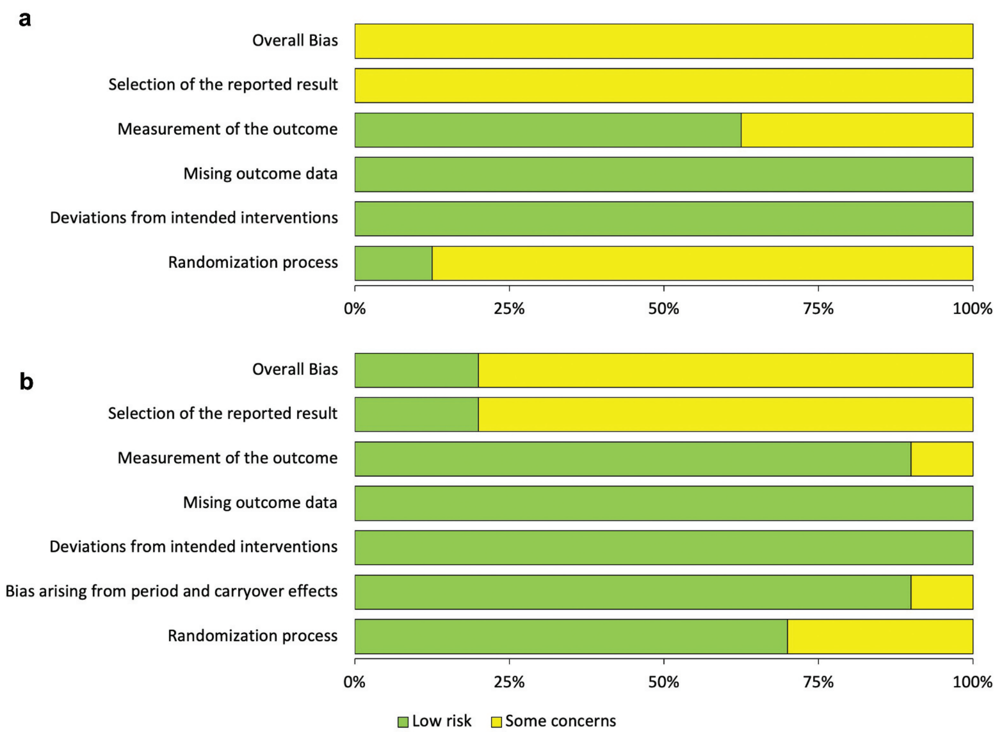

Figure 2. Risk of Bias Tool V.2. (a) Risk of bias per domain across studies with a parallel design; (b) Risk of bias per domain across studies with a crossover design.

measurement of the outcome, and randomization process were the domains that raised concerns in some of the studies. The overall bias across crossover randomized controlled trials ($n = 10$) was judged as low risk for the two studies and raised some concerns for the remaining studies (Figure 2B).

3.3. Caffeine and caffeinated energy drinks

Four studies investigated the effects of beverages with added caffeine in athletic performance of male and female soccer players [25–28]. One study examined the effect of Red Bull® on repeated sprint performance in 15 competitive female soccer players [25]. Participants performed three sets of eight bouts of the modified t-test after ingestion of 255 mL of placebo or Red Bull®, 1 hour (h) of pre-exercise in a randomized placebo-controlled crossover design. Throughout testing, sprint time, heart rate (HR), and rating of perceived exertion (RPE) were continuously recorded. Repeated-measures analysis of variance was used to examine differences in variables between drink conditions. Across athletes, average t-test time ranged from 10.4 to 12.7 seconds (sec). The mean sprint time was similar ($p > 0.05$) between Red Bull® (11.31 ± 0.61 sec) and placebo (11.35 ± 0.61 sec). The results indicate that 255 mL of Red Bull® containing 1.3 mg of caffeine per kg of body mass and 1 g of taurine does not alter repeated sprint performance, RPE, or HR in female soccer players compared to placebo. Another study with Red Bull® investigated the effects of a caffeine-containing energy drink on soccer performance during a simulated match in 19 male soccer players [26]. Participants ingested 630 ± 52 mL of a commercially available energy drink (sugar-free Red Bull®) to provide 3 mg of caffeine per kg of body mass, or a decaffeinated control drink. After 60 minutes (min), the players performed a 15 sec maximal jump test, a repeated-sprint test (7 × 30 meters (m); 30 sec of active recovery) and played a simulated soccer match. Individual running distance and speed during the match were measured using global positioning satellite (GPS) devices. In comparison to the control drink, the ingestion of the energy drink increased mean counter-movement jump (CMJ) height (34.7 ± 4.7 vs 35.8 ± 5.5 cm; $p < 0.05$), mean running speed during a repeated sprint ability test (25.6 ± 2.1 vs 26.3 ± 1.8 km/h; $p < 0.05$) and total distance covered at a speed higher than 13 km/h during the match (1205 ± 289 v 1436 ± 326 m; $p < 0.05$). In addition, the energy drink increased the number of sprints during the whole match (30 ± 10 vs 24 ± 8; $p < 0.05$). Lara et al. also studied the effectiveness of a caffeine-containing energy drink (Fure®) to improve the physical performance in female soccer players during a simulated soccer match [26,27]. Besides caffeine, this energy drink formula contained taurine (18.7 mg/kg), sodium bicarbonate (4.7 mg/kg), and L-carnitine (1.9 mg/kg), substances also present in the placebo drink, prepared by the manufacturer of the caffeinated drink. In two different sessions, 18 players ingested 3 mg of caffeine per kg of body mass in the form of an energy drink or an identical drink with no caffeine content (placebo). After 60 min, players performed a CMJ test, and a 7 × 30 m repeated sprint test followed by a simulated soccer match (2 × 40 min). Individual running distance and speed were measured using GPS devices. In comparison to the placebo drink, the ingestion of the caffeinated energy drink increased the CMJ height (26.6 ± 4.0 vs 27.4 ± 3.8 cm; $p < 0.05$) and the average peak running speed during the repeated sprint test (24.2 ± 1.6 vs 24.5 ± 1.7 km/h; $p < 0.05$). During the simulated match, the energy drink increased the total running distance (6,631 ± 1,618 vs 7,087 ± 1,501 m; $p < 0.05$), the number of sprints (16 ± 9 vs 21 ± 13; $p < 0.05$) and running distance covered at >18 km/h (161 ± 99 vs 216 ± 103 m; $p < 0.05$).

One study examined the effects of post-activation potentiation (PAP), with and without prior caffeine ingestion, on CMJ performance of 12 professional male soccer players [28]. Participants performed two trials of plyometric exercises and sled towing 60 min after placebo or caffeine ingestion (5 mg per kg of body mass) in a randomized, counterbalanced, and double-blinded design. CMJ performance was assessed at baseline and 1, 3 and 5 min after the conditioning stimulus (T1, T3, and T5, respectively). A significant difference in the jump height was observed after the PAP protocol (F [3,11] = 14.99, $p < 0.001$, partial $\eta 2 = 0.577$). The analysis also indicated a significant difference in CMJ performance across conditions, with caffeine eliciting a greater response (F [1,11] = 10.12, $p = 0.009$, partial $\eta 2 = 0.479$). Jump height was increased at T1, T3, and T5 in caffeine condition (5.07%, 5.75%, and 5.40%, respectively; $p < 0.01$) compared to baseline. In the placebo condition, CMJ performance was increased at T3 (4.94%; $p < 0.01$) only. CMJ height was higher in the caffeine condition at T1, T3, and T5 ($p < 0.05$), but not at the baseline ($p > 0.05$) compared to placebo.

Bassini et al. [22] studied the effects of caffeine supplementation on the ammonia and amino acid metabolism of elite soccer players. In this double-blind randomized study, athletes ($n = 19$) ingested a caffeine capsule with 5 mg per kg of body mass or a placebo capsule after a standardized breakfast. An hour later, players did a 15 min warm-up and performed two 45 min sessions of a variable-distance-run protocol with a 15 min interval. After the protocol, players performed the Yo-Yo Intermittent Recovery Test level 2 (Yo-Yo IR2) until exhaustion. Increases in serum caffeine after supplementation followed two significantly different patterns, therefore players were divided into three different groups: control (no caffeine intake); supplemented players with low caffeine absorption (<900% increase, $n = 5$) and supplemented players with high caffeine absorption (>10,000% increase, $n = 6$). Nevertheless, no significant differences in velocity (km/h) and distance (m) during the Yo-Yo IR2 were observed between supplemented and non-supplemented players (control group = 12.3 ± 0.3 km/h, 1449 ± 378 m; low caffeine absorption = 12.2 ± 0.5 km/h, 1540 ± 630 m; high caffeine absorption = 12.3 ± 0.5 km/h, 1367 ± 330 m).

Ranchordas et al. investigated the acute use of caffeinated gum (200 mg of caffeine) in 10 male soccer players [29]. On two occasions, players chewed caffeinated gums or a placebo for 5 min (expecting 85% of the caffeine dose to be released within this period) before performing a maximal CMJ, a 20 m sprint test and the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IR1). Performance on the 20 m sprint was not different between trials, but players taking caffeine covered 2.0% more distance during Yo-Yo IR1 ($d = 0.33$) and increased CMJ height by 2.2% ($d = 0.3$). Athletic performance was improved by chewing caffeinated gum, although the effect sizes were small.

3.4. Creatine

Four studies investigated the effects of creatine usage in elite soccer players, either combined with sodium bicarbonate [33] or alone (as creatine monohydrate [30,31] or magnesium creatine chelate [32]). Creatine supplementation protocols were different between studies, with daily doses from 5 to 20 g, and supplementation periods from 6 days to 16 weeks.

One study investigated the effects of creatine (20 g per day) combined with sodium bicarbonate (0.3 g per kg of body mass per day), split into four equal daily doses for 7 days, on soccer-specific performance in 20 elite male soccer players [33]. The combination of creatine and sodium bicarbonate improved time in the 30 m sprint and arrowhead agility test. However, the 10 m sprint time and distance covered in the Yo-Yo IR1 showed no differences between groups.

Mujika et al. [30] assessed the effect of the same daily dose of creatine (5 g of creatine monohydrate, four times a day for 6 days) in 17 highly trained male soccer players. Participants performed a CMJ test, a repeated-sprint test consisting of 6 × 15 m +30 sec of recovery, an intermittent endurance test consisting of 40 × 15 sec bouts of high-intensity running interspersed by 10 sec bouts of low-intensity running and a recovery CMJ test consisting of three jumps on two occasions, 7 days apart. Average 5 m and 15 m times during the repeated-sprint test improved in the intervention group. Recovery CMJ (i.e. % of the performance attained in the resting CMJ) performance remained unchanged post-supplementation, but not in the placebo group. No significant changes were observed in jump height and distance covered during the intermittent endurance test.

Another study [31] investigated the effects of a six-week plyometric training and creatine supplementation (20 g per day during 1 week followed by 5 g per day during 5 weeks) on maximal-intensity and endurance performance in 30 female soccer players during in-season training. Creatine supplementation improved squat jump (SJ), CMJ, and running anaerobic sprint test performance (6 × 35 m maximal sprints), compared with placebo and control groups.

Finally, Zajac et al. [32] investigated the impact of daily supplementation with 5.5 g of magnesium creatine chelate during 16 weeks on running anaerobic sprint performance in 16 elite male soccer players. Participants performed a running anaerobic sprint test (6 × 35 m maximal sprint efforts, separated by 10 sec of active recovery) five times, and total time, average power, and maximum power were measured on each occasion. Long-term supplementation with magnesium creatine chelate supplementation improved the running anaerobic sprint test time and power (average and maximum).

3.5. Protein

Two studies examined the effects of protein supplementation on the athletic performance of elite soccer players. One study compared the effects of whey protein isolate and soy protein isolate supplementation on field performance deterioration over successive training sessions [34]. Ten well-trained male soccer players increased their daily protein intake from 0.8 to 1.5 g per kg of body mass by adding two different protein supplements (from whey and soy) for 10 days. Both whey and soy protein supplementation mitigated the decrease in high-intensity and high-speed running during trials but did not affect CMJ performance, 10 m and 30 m sprinting time, and repeated sprint ability fatigue index. Another study [35] compared the ingestion of milk protein concentrate with an energy-matched placebo for 7 days during a simulated in-season microcycle with two matches performed 3 days apart and four daily practices. Twenty competitive male soccer players completed two trials (one with consumption of maltodextrin placebo and another with protein consumption), separated by a 3-week wash-out period. Before the first trial, during 2 weeks of an adaptive period, participants were given a dietary plan with a standard protein intake of 1 g per kg of body mass per day. During the protein trial, players received a 20 g dose of milk protein supplement (80% casein, 20% whey) on training days, and 80 g of the same supplement in the 6 h following the match (25 g immediately after the match, 30 g, 3 h after the match and again 25 g 6 h after the match). Protein supplementation daily dose ranged from 0.26 to 1.15 g of protein per kg of body mass on training and match days, respectively. Speed, jump height, and isokinetic peak torque were measured before the first match (day 1 of the trial) and daily thereafter for six days. Players following the protein supplementation trial showed some considerable differences in athletic performance indicators, when compared to placebo trials. For example, during the protein trial, total distance remained unaffected in the second match compared to the first (but not in the placebo trial). Also, distance covered when running at >14 km/h declined 5.7% between matches in the protein trial, against 11% in the placebo trial. Finally, the number of accelerations and decelerations also decreased to a lesser extent during the protein supplementation trial, when compared to placebo: 1% reduction of accelerations in protein trial against 2% reduction in placebo; 1% reduction of decelerations in protein trial against 2.6% in placebo.

3.6. Beverages with carbohydrates and electrolytes

Abbey and Rankin investigated the effects of beverages with carbohydrates and electrolytes on the athletic performance of elite soccer players [36]. The authors compared the effect of a honey-sweetened beverage with those of a commercial sports drink and a placebo on performance in a 90 min soccer simulation. Ten experienced male soccer players randomly performed three trials (honey-sweetened with added sodium, sports drink, and placebo), consuming the beverage before and during halftime for a total of 1.0 g of carbohydrates per kg of body mass for honey and sports drinks. Performance measures included five sets (T1–T5) of a high-intensity run and agility and ball-shooting tests, followed by a final progressive shuttle-run test to exhaustion. For the high-intensity run test, T2–T5 (48.5 ± 1.6, 49.0 ± 1.7, 48.7 ± 1.4, and 49.5 ± 1.5 sec) were significantly slower than T1 (42.6 ± 1.1 sec), but no main effect of intervention or interaction between time and intervention was observed. A decrease in time to exhaustion for the progressive shuttle-run test was observed from baseline for all interventions (−22.9% ± 5.8%), with no main effect for intervention.

3.7. Tart cherry juice

One research study investigated the effects of tart cherry juice on muscle function after a 90 min soccer match in 10 male professional players [41]. Participants consumed two daily 30 mL servings of tart cherry juice or an isocaloric cherry-flavored control drink (one in the morning and another after training or match), starting in the morning of the match and ceasing at 36 h after the match. CMJ and reactive strength index were measured before and 12, 36, and 60 h after each match. CMJ height was similarly reduced in the days after the match after both tart cherry juice and placebo ingestion, with the greatest loss occurring at 12 h post-match (−5.9% ± 3.1% vs −5.4% ± 2.9% of baseline values, respectively; $p = 0.966$, ηp2 = 0.010). Decrements in the reactive strength index were also greatest at 12 h post-match (tart cherry juice −9.4% ± 8.4% vs control −13.9% ± 4.8% of baseline values), but no group differences were observed at any time point ($p = 0.097$, ηp2 = 0.205).

3.8. Nitrate-rich beetroot juice

One study [38] examined the effects of nitrate-rich beetroot juice on athletic performance after a simulated soccer match. Thirteen semiprofessional male soccer players received either beetroot juice or placebo twice daily (150 mL each time, ~500 mg of nitrate daily) for seven days (three days pre-exercise, on the trial day, and three days post-exercise). After completing the Loughborough Intermittent Shuttle Test (LIST), the athletic performance [SJ, CMJ, maximal voluntary contraction (MVC), and 20-m sprint] was assessed at a baseline of 0, 24, 48, and 72 h following exercise. A decrease was observed in CMJ, MVC, and 20 m sprint performance at 0, 24, and 48 h , respectively, in both conditions. However, compared to the placebo, the performance decrease was significantly attenuated with beetroot juice for CMJ at 24 and 48 h, for MVC at 0, 24, and 48 h, and for the 20 m sprint at 48 h after the test.

3.9. Sodium and potassium bicarbonate, with potassium, magnesium, and calcium citrate

Another study [23] evaluated the effectiveness of a supplementation protocol with sodium and potassium bicarbonate and minerals (potassium, magnesium, and calcium) on anaerobic performance using a repeated anaerobic sprint test (6 × 30 m sprints, separated by 10 sec of active recovery). In the experimental group, 13 male elite soccer players, ingested a single dose of 3000 mg sodium di-carbonate, 3000 mg potassium di-carbonate (6 capsules containing 500 mg each), 1000 mg (600 mg +400 mg) calcium phosphate and calcium citrate, 1000 mg potassium citrate, and 1000 mg magnesium citrate twice a day, 90 min before each training session. The total time spent in a repeated anaerobic sprint test was significantly reduced ($d = 0.984$) in players supplemented with sodium bicarbonate and minerals.

3.10. Yohimbine

Ostojic et al. [39] aimed to determine the effects of yohimbine supplementation on exercise performance in 20 male professional soccer players. Before and after the supplementation protocol (10 mg of yohimbine HCl twice a day for 21 days), each participant performed several tests (bench press, leg press, vertical jump, power test, and endurance shuttle run). No within- or between-trial changes were observed.

3.11. Resurgex plus®

Finally, one study [40] determined the impact of a nutraceutical blend on the performance of 24 male soccer players. Performance tests were conducted at the beginning and end of a pre-season camp, using a progressive maximal treadmill test to exhaustion to determine the velocity at the lactate threshold, VO_{2max} and time-to-exhaustion. Supplemented players received a nutraceutical blend (Resurgex Plus®) twice daily for 20 days. The nutraceutical blend was composed of the following: 75 mg of CoQ10, 500 IU SOD/Gliadin, 1750 mg of ornithine ketoglutarate, 300 mg of L-Carnitine, 100 mg of nucleotides, 750 mg of D-ribose, 500 mg of L-glutamine, 100 mg of beta-glucans, 12.5 mg of fruit polyphenols, and 1750 mg of branched-chain amino acids. Preseason training significantly improved performance, as indicated by increased lactate threshold, VO_{2max} and time-to-exhaustion, in both supplemented and placebo groups, but no significant differences were detected depending on supplementation.

4. Discussion

The aim of the present systematic review was to assess available evidence regarding the use of dietary supplements on athletic performance of highly trained and elite soccer players. Although some of the products used in the studies retrieved by our search are not considered dietary supplements according to European Food Safety Authority (EFSA) definition [42] (e.g. caffeinated energy drinks or protein powders), we opted to include them in this review. Indeed, these products are often used as ergogenic and as a complement to players' regular diets, thus matching the criteria used by the IOC to define dietary supplements, which we believe are the most appropriate for the scope of this review. Caffeine supplementation in doses between 3 and 6 mg per kg of body mass may improve jump height and sprint ability, particularly in female players. Still, individual response to caffeine must be considered, as results can change considerably in supplemented players. Creatine may improve sprint time, agility test time, and, in female players, jump performance. Protein supplementation can improve maximum speed, sprint time, and jump height between matches, especially if protein ingested from food is not up to recommendations. Beverages containing carbohydrates and electrolytes can be used as part of the strategies to achieve carbohydrate intake during training and match-day, but used alone do not benefit athletic performance. Tart cherry juice might be useful for maintaining athletic performance after matches that produce higher force loss and exercise-induced muscle damage, but polyphenols from the diet might attenuate the effects of tart cherry supplementation. Nitrate-rich beetroot concentrate can be a valid strategy to attenuate performance decrease in the days following matches. Further investigation with sodium bicarbonate is necessary, as improvements in repeated anaerobic sprint performance of soccer players were observed when sodium bicarbonate was supplemented among with minerals. Finally, the available data does not support yohimbine supplementation or the use of Resurgex Plus® to improve athletic performance in elite soccer players.

4.1. Caffeine and caffeinated energy drinks

Caffeine is well known to benefit athletic performance [19,43]. Despite differences in individual response to caffeine ingestion and side effects associated with high doses (e.g. nausea, tremors, anxiety, insomnia), the benefits on athletic performance are somewhat consistent [43]. For soccer players, recommendations range between 3 and 6 mg of caffeine per kg of body mass ingested approximately 60 min before exercise or 1 and 2 mg per kg of body mass ingested before kickoff and at half-time [2]. Still, there are some challenges to caffeine use among elite soccer players. For example, soccer matches are frequently played late in the evening, making it necessary to consider the benefits of caffeine ingestion against the sleep impairment it might cause. Substitute players may also abstain from taking caffeine before the match due to the possibility of not playing, leading them to miss caffeine-related benefits if called to play.

The current systematic review identified four studies investigating the usage of beverages containing caffeine for elite soccer players athletic performance. Two studies used Red Bull® [25,26] in regular (i.e. with carbohydrates) and sugar-free versions. Although not considered dietary supplements by EFSA definition [42], we opted to include studies with energy drinks in this review, as they are often perceived by athletes as ergogenic and are used because of their caffeine content. Additionally, in these studies, caffeine intake was measured in mg per kg of body mass, making it possible to compare effects with other caffeine supplements' formats. Astorino et al. reported no main effect ($p = 0.68$) of Red Bull® on sprint performance in female soccer players, but a clear variation in individual responses to caffeine ingestion was observed [25]. In this study, all participants ingested the same amount of caffeine (80 mg present in one 255 mL can), despite a different body mass (63.4 ± 6.1 kg), meaning caffeine intake was under the dose normally considered ergogenic (3 to 6 mg per kg of body mass). In a separate study, Del Coso et al. compared the use of Red Bull® sugar free with other carbonated soft drinks (zero sugar, zero caffeine). Beverage volume was adjusted for each participant's body mass, aiming to provide a dose of 3 mg of caffeine per kg of body mass. The ingestion of the caffeinated beverage increased jump height, the ability to perform repeated sprints, the total running distance during a simulated match, and the distance covered at high intensity. Nevertheless, analysis of individual data shows that the two subjects improved outcomes in two performance tests with the decaffeinated control drink, while no subject increased performance with the decaffeinated control drink in all three performance tests. Since Red Bull® contains other ingredients beside caffeine (taurine, glucuronolactone and B-group vitamins), not present in the decaffeinated beverage, it might be questioned if ergogenic effects are due to the presence of these substances. For this reason, another study compared two identical beverages (Fure®), which composition was adjusted to participants' body mass: taurine (18.7 mg/kg), sodium bicarbonate (4.7 mg/kg), and L-carnitine (1.9 mg/kg) [27]. Thus, the experimental trials differed only in the amount of caffeine ingested (0 mg with placebo vs 173 ± 23 mg with the caffeinated drink). This study demonstrated that 3 mg of caffeine per kg of body mass in the form of an energy drink enhanced jump height, the ability to perform repeated sprints, the total running distance, and the distance covered at high intensity and sprint velocity during a simulated match in female soccer players, but no data on individual variations was available.

Guerra Jr. et al. [28] examined whether acute caffeine ingestion augmented the effect of a plyometric and sled towing potentiating stimulus on CMJ performance. Participants ingested 5 mg of caffeine per kg of body mass, diluted in 250 mL of artificially sweetened water or 250 mL of a placebo drink similar in taste. The results of this study suggest that acute plyometric and sled towing stimuli enhances jump performance and that this potentiation is enhanced by caffeine ingestion in male soccer players. Although individual responses should be considered, the synergistic effects of post-activation potentiation and caffeine ingestion may be beneficial for athletes enrolled in activities that depend on strength and power. The combination of caffeine ingestion alongside a potentiating conditioning stimulus also offers strength and conditioning coaches a practical and legal means by which short-term, explosive exercise performance may be enhanced for up to 5 min.

Bassini et al. [22], in their study about the effects of caffeine on the ammonia and amino acid metabolism of elite soccer players, found no significant difference in athletic performance because of caffeine supplementation. But even with a dose of 5 mg of caffeine per kg of body mass, Yo-Yo IR2 speed and distance were not significantly different among players ingesting caffeine or placebo. The fact that players exercised after breakfast and with access to a glucose drink *ad libitum* throughout the training might have contributed to attenuating caffeine's impact on performance outcomes between groups. Even if the number of participants was reduced ($n = 19$), individual data is not published. This makes it more difficult to understand if some individuals benefited from caffeine supplementation beyond the similarities among groups.

Additionally, one study [29] with caffeinated gum revealed discrete benefits on Yo-Yo IR1 performance (2% enhancement compared to placebo) and increased CMJ height (by 2.2% compared to placebo). This modest impact, statistically significant but with low significance in performance, may be explained by the reduced caffeine dose (200 mg, equivalent to 2.7 ± 0.2 mg per kg of body mass). These small improvements were observed even with caffeine gum being chewed for 5 min after the warm-up and just before performing the fitness tests. Caffeine is absorbed much faster via the buccal mucosa compared with ingestion via pills or powders [44]. Thus, caffeinated gum might be an option for substitute players at half-time or when extra-time is played. Further studies with higher doses per gum (or chewing more gums to achieve the recommended caffeine dose) or with gums chewed before kickoff and at half-time could prove the validity and versatility of this format in elite soccer players.

Overall, caffeine supplementation can be considered a valid strategy to improve athletic performance in male and female elite soccer players, as long as individual responses to caffeine are observed, and a dose between 3 and 6 mg per kg of body mass is ingested 60 min prior to exercise.

4.2. Creatine

Oral creatine supplementation can increase muscular creatine concentration [45]. Given its role in ATP regeneration during short recovery periods of intense exercise, creatine can benefit athletic performance in several ways [46]. Among the included studies, creatine supplementation improved different athletic performance outcomes, no matter the form of supplementation. Although creatine monohydrate is the most commonly available in dietary supplements, it remains unknown if different forms of creatine supplements induce different results in performance tests or if the observed benefits resulted from the combination with other ingredients. Nevertheless, existing reviews did not report the benefits of other creatine formulas over creatine monohydrate for the same amount of creatine [47,48]. Regarding the ingestion protocol (i.e. with or without a loading phase), supplementation with high doses (20 g per day) for one week among male players maintained CMJ performance [30], but showed benefits in repeated sprint time [30], sprint time (10 and 30 m) and agility test time [33]. In female players, the same creatine supplementation protocol improved jump height and maximal sprint (6×35 m) [31]. This suggests that creatine supplementation can be used to improve athletic performance during training and adaptation periods, but also to prevent or minimize decrease in performance during matches. It is worth noting that protocols with a loading phase were associated with body mass increases. Ingesting higher doses of creatine (above 0.03 g per kg of body mass per day) can increase body mass, particularly in the short term, mainly due to water retention [47,49]. Therefore, this should be considered when choosing creatine supplementation protocols in soccer players since some individuals might be more sensitive to weight changes. Additionally, a protocol with a lower dose (5 g per day) throughout the competitive season (16 weeks) also revealed to improve repeated anaerobic sprint performance [32].

In resume, creatine supplementation with a loading phase or lower continuous dose can be valuable for improving or maintaining athletic performance throughout the different stages of the competitive season in elite male and female soccer players.

4.3. Protein

Both included studies investigated the impact of protein supplementation on the athletic performance of elite soccer players but with different goals. One study compared the effects of whey and soy protein supplementation on recovery kinetics after speed endurance training [34]. Increasing daily protein intake to 1.5 g per kg of body mass, either from whey or soy, could help to mitigate field performance (i.e. the maximum and average speed, high-intensity running, high-speed running, and intense accelerations and decelerations) deterioration during successive speed-endurance training sessions. The daily protein ingestion in the placebo group (0.8 g per kg of body mass) was about half the amount ingested by the supplementation group and under daily protein ingestion observed in several studies enrolling soccer player [50–52], which might explain the observed differences between groups. As daily protein intake for elite soccer players is within the recommended range (1.6–2.2 g per kg of body mass) [2,53], supplementation should only be considered in players with known low intake of protein. Still, it is worth to note that increasing daily protein intake via supplementation can be useful to improve resistance training adaptations and increase lean body mass in athletes [54], although, to our knowledge, there are no studies conducted with elite soccer players.

Another study [35] examined the effects of milk protein supplementation on performance, recovery, and inflammatory responses during a simulated seven-day congested fixture with two matches disputed 3 days apart. Differences in 10 and 30 m sprint time, CMJ height, and concentric and eccentric isokinetic peak torque of the knee extensors and knee flexors were tested in the placebo and protein groups. Players supplemented with a protein ingested 1.05 ± 0.04 g of protein per kg of body mass per day in the adaptative period and 2.38 ± 0.07 g per kg of body mass per day on match days, while players in the placebo group ingested 1.03 ± 0.05 and 1.33 ± 0.01 g per kg of body mass per day, in the same periods. As discussed above, daily protein intake in the placebo group was below current recommendations and the generally observed intakes in elite soccer players. Still, increased protein ingestion (from food or dietary supplements) may improve neuromuscular performance, since it can increase skeletal muscle fatigue resistance or reduce skeletal muscle performance deterioration after damaging exercises [55,56]. A possible explanation for the improvement in recovery kinetics of soccer-specific performance is protein-induced attenuation of the inflammatory response because increasing protein intake may attenuate C-reactive protein and myeloperoxidase elevation following a muscle damaging protocol [57].

Although most research in protein supplementation is focused on muscle mass gains or recovery after exercise-induced muscle damage and is rarely studied within elite soccer players, it is safe to recommend protein supplementation when intake does not reach current recommendations (i.e. 1.6 and 2.2 g per kg of body mass [2,53]). Also, protein adequately distributed throughout the day (i.e. ingesting 20–40 g of protein six times a day) and after intense exercise can benefit soccer players, especially when limited time separates matches [58].

4.4. Beverages with carbohydrates and electrolytes

Carbohydrates and fluids are key for athletic performance in soccer; carbohydrates represent a primary fuel source for the muscles during high-intensity activities, and fluids regulate several important mechanisms in the body during exercise [2]. Thus, since the 1990s, there has been an interest in the role of beverages containing carbohydrates and electrolytes in athletes' performance. Studies with these beverages, often called sports drinks, have shown benefits in activities such as endurance sports and among younger and amateur soccer players [59–62], but only one study with elite soccer players was found [36]. In this work, the authors found no differences in athletic performance after ingesting either a honey-sweetened beverage with added sodium, a commercially available sports drink (Gatorade®) or placebo (non-caloric sweetened beverage). This lack of ergogenic effect might be explained by the reduced amount of carbohydrates present in the ingested beverages during the experimental protocol – 1.0 g per kg of body mass. This amount is under current recommendations for carbohydrate intake before and during match (1–3 g per kg of body mass) [2]. Another important aspect regarding the use of sports drinks for athletic performance purposes is the ratio between volume and carbohydrate content. The average carbohydrate content in sports drinks is 6%, meaning that a typical 500 mL bottle can provide about 30 g of carbohydrates, a relatively small amount. Thus, sports drinks containing carbohydrates and electrolytes can be used as part of the strategies to achieve carbohydrate intake in training and match-days, but alone are not enough to benefit athletic performance in adult, elite soccer players.

4.5. Tart cherry juice

Tart cherry juice has been used as a recovery drink among athletes, mainly because of its phenolic and anthocyanin content. These components can impact markers of antioxidant status and systemic inflammation, particularly after intense exercise [63]. Nevertheless, there are only two available studies investigating tart cherry supplementation among soccer players: Bell et al. suggested Montmorency tart cherry concentrate could be effective in accelerating recovery following prolonged, repeat sprint activity in semiprofessional soccer players [64]; by the contrary, Abbott et al., concluded that tart cherry juice did not hasten recovery after a soccer match in professional players [41]. These contradictory results might be explained by differences in participants competitive level, since the level of force loss and exercise-induced muscle damage resulting from the experimental protocol was only mild in the case of elite players. Furthermore, Abbott et al. did not refrain participants from consuming their usual diet, including fruits and vegetables with a high polyphenol content [41]. In other studies, authors excluded the intake of high polyphenol sources from participants' diet during testing [64–66]. This suggests that a sufficient amount of polyphenols from the diet might attenuate the effects of tart cherry supplementation, and an additional intake of these nutrients might have no further benefits.

In resume, although no benefits from tart cherry juice supplementation were yet observed in the recovery of elite soccer players, more research is needed to understand what type of tart cherry supplement can be most effective, what dose is optimal and for how long should it be used. The correct timing to initiate tart cherry supplementation (i.e. before the end of the match or just after the match) should also be addressed in the future research.

4.6. Beetroot juice

One study [38] assessed the effect of nitrate-rich beetroot concentrate on the recovery kinetics of physical performance, muscle damage, and perceived muscle soreness after a simulated soccer match. Beetroot and its concentrates are rich in dietary nitrates, known to increase plasma nitrite and nitric oxide [67]. Increasing the amount of nitric oxide may be valuable for athletic performance since it reduces the oxygen cost of exercise and ATP cost of force production [68]. Several studies investigated the impact of nitrite on athletic performance, including cardiorespiratory endurance, sprint exercise, and cognitive function [69–71]. Regarding soccer, Nyakayiry et al. [72] concluded that ingesting beetroot juice (~800 mg nitrate per day) improved high-intensity intermittent exercise performance in amateur players. Although previous studies have focused on the effects of nitrate-rich beetroot juice for improving athletic performance [70,71,73], the work of Daab and colleagues [38] observed benefits during recovery. Presumably, approximately 500 mg nitric oxide per day for seven days may help maintain athletic performance during recovery (up to 3 days after the match), even if blood markers of muscle damage were not changed by nitrate-rich beetroot juice supplementation. Elite soccer players may be highly exposed to congested calendars, often playing more than one match per week. Therefore, chronic ingestion of nitrate-rich beetroot concentrate can be valid to attenuate performance decrease in the days following soccer matches.

4.7. Sodium and potassium bicarbonate, with potassium, magnesium, and calcium citrate

Ergogenic effects of muscle acidosis buffering agents, such as sodium bicarbonate, have been investigated for a long time [74]. Ingesting sodium bicarbonate has been suggested to attenuate exercise-induced muscle acidosis and improve athletic performance, although the literature has reported mixed results regarding ergogenic effects in soccer [75]. These discrepancies in the results of empirical research with buffering might be related to differences in the type of participants, applied exercise protocols, dosage and timing of supplement ingestion, and composition of the buffering supplements [76]. One study [23] demonstrated a significant reduction in running-based anaerobic sprint test (RAST) performance among elite soccer players supplemented with sodium and potassium bicarbonate along with calcium phosphate, potassium citrate, and magnesium citrate. The improvements in anaerobic performance were caused by increased resting blood pH and bicarbonate levels. As players were supplemented with bicarbonate (3-g tablet, twice daily for 9 days) combined with minerals (calcium, magnesium, and potassium) known to impact muscular activity, making it difficult to impute observed results just for sodium bicarbonate. Furthermore, in one study with soccer semiprofessional adolescent players [77], sodium bicarbonate did not improve RAST performance. Gastrointestinal distress caused by sodium bicarbonate should also be considered, as it can inhibit performance gains. Several factors may impact the prevalence and intensity of gastrointestinal disturbance, such as dose, timing of ingestion, presentation, and if sodium bicarbonate is taken with meals [75]. To resume further investigation with sodium bicarbonate in soccer players is necessary. The scarce number of studies is likely the main reason for its recognized lack of use in elite soccer [2].

4.8. Yohimbine

Yohimbine is an herbal preparation from the bark of the yohimbe tree (*Pausinystalia johimbe*) usually used in supplements designed for fat loss, sexual health, or physical performance. This alkaloid is rapidly absorbed, with peak levels following ingestion appearing between 20 and 30 min, and fully eliminated 60 min post-ingestion [78]. Studies about the impact of yohimbine on athletic performance [79–81] are limited and inconsistent (different populations, doses and protocols, and different ingredients associated with yohimbine hydrochloride), with just one work conducted with soccer players [39]. A review of the effects of yohimbine supplementation on performance did not show consistent benefits in athletic performance, particularly in repeated sprints, and even raised questions about side effects and toxicity [80]. Overall, available data does not support the recommendation of yohimbine supplementation to improve athletic performance in elite soccer players. Additionally, it should be mentioned that in 2013 the EFSA Panel on Food Additives and Nutrient Sources added to Food provided a scientific opinion evaluating the safety in use of yohimbe bark and its preparations [82], stating that the chemical and toxicological characterization of yohimbe bark and its preparations for use in food are not adequate to conclude on their safety as ingredients of food supplements.

4.9. Resurgex Plus®

Substances with antioxidant activity have long aroused interest among athletes based on the belief that antioxidants can improve immune function, reduce fatigue, accelerate recovery, or improve performance [83]. Aside from supplements with vitamins A, C, or E and polyphenols, several nutraceutical blends have been developed to allegedly support athletic performance, and currently several brands market products with this type of claim. For instance, one study [40] examined changes in athletic performance, muscle damage, and oxidative stress markers in soccer players during the preseason by using a specific nutraceutical blend, composed by 75 mg CoQ10, 500 IU of superoxide dismutase, 1750 mg of ornithine ketoglutarate, 300 mg of L-Carnitine, 100 mg of nucleotides, 750 mg of D-ribose, 500 mg of L-glutamine, 100 mg of beta-glucans, 12.5 mg of fruit polyphenols, and 1750 mg of BCAA. It has been hypothesized that this supplement could reduce oxidative stress and creatine kinase responses compared to an isocaloric equivalent without the nutraceutical blend in response to a maximal exercise test. Velocity at the lactate threshold, time to exhaustion, and VO_{2max} were measured in two trials 20 days apart during the preseason. Differences observed between trials and groups (Resurgex® vs. placebo) were not significant, and improvements in athletic performance indicators could possibly be attributed to regular preseason training. This study was the only one investigating Resurgex® in soccer players, but other authors assessed the possible benefits of antioxidants supplementation in performance. A recent review [84] highlighted the potential harms of supplementation with high doses of antioxidants for athletes. There is no evidence to support the benefits of antioxidant supplementation in acute physical efforts, and exogenous antioxidants can impair some physiological functions of free radicals needed to enhance training adaptations [85–87]. However, existing studies were conducted with non-elite soccer players. Thus, a food-first approach focused on a diverse, balanced, and nutrient-rich diet is more consensual among experts working with elite soccer players [2].

5. Conclusions

The present systematic review was the first to approach dietary supplements for athletic performance exclusively in highly trained and elite soccer players, according to tiers defined by McKay et al. [21]. Consequently, this might have conditioned the number of eligible studies to be included and might be limited to providing information on many other substances currently available (and used) in elite soccer (e.g. vitamins, probiotics, or omega 3 fatty acids).

Various factors may prevent studies from being conducted with higher-level soccer players, making data in this area scarce. For instance, elite players' longer competitive calendars mean less time for participating in intervention studies, or elite players may feel less available to participate. Therefore, health and performance support teams should be cautious in interpreting available evidence. The results of this systematic review may contribute to increasing confidence in using dietary supplements such as creatine monohydrate, protein, and caffeine. Nitrate and tart cherry supplementation, typically available in the form of drinkable concentrates, should be evaluated mindfully, as its efficacy depends on several factors. Finally, several substances still lack evidence for performance benefits in highly trained players, meaning extra caution should be taken when considering its use – in the case of yohimbine, its use is strongly discouraged.

Elite soccer players should seek appropriate nutritional support, meaning better, evidence-based practices regarding food and nutritional strategies. Dietary supplements may be valuable and convenient for meeting players' nutritional requirements, but this review reinforces that their use requires a critical sense of safety and effectiveness. Regularly providing supporting teams with training regarding dietary supplementation can increase their knowledge and confidence, leading to better advice for athletes. Finally, more research on top-tier male and female soccer players is needed to better understand the validity of dietary supplements for highly trained athletes.

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