Journal of Science in Sport and Exercise
https://doi.org/10.1007/s42978-024-00297-6

REVIEW ARTICLE

Dietary Supplementation Strategies for Improving Training Adaptations, Antioxidant Status and Performance of Volleyball Players: A Systematic Review

Ricardo E. Hernández-Landa[1] · Milton Lazo[1] · Daniela D. Salado[1] · Elizabeth Sánchez-Almanzar[1] · Jenny L. Cepeda-Marte[1] · Reza Zare[2,3] · Ali Ali Redha[4,5] · Tom Clifford[6]

Received: 7 April 2024 / Accepted: 24 May 2024

Abstract

Purpose Volleyball demands high physical performance including agility, speed, endurance and muscular strength. As volleyball players explore methods to achieve efficiency in these areas, nutritional supplementation has been considered a valuable adjunct to accomplish this goal. This systematic review aimed to comprehensively explore the effects of different dietary supplementation strategies on the training adaptations, antioxidant status and performance of volleyball players.

Methods A search was conducted in PubMed, Web of Science, Cochrane, Google Scholar, and EbscoHost on 28th July 2023 and updated on 12th May 2024. Studies were included if the participants were volleyball players, taking a dietary supplement and evaluated sports-related outcomes. The risk of bias was assessed using Cochrane's revised risk of bias tool, RoB2.

Results The review included 19 trials investigating supplements such as branched-chain amino acids (BCAA), creatine, *N*-acetylcysteine (NAC), hydroxy-methyl-butyrate (HMB), grape seed extract (GSE), nitrate, caffeine, iron and magnesium. Outcomes including vertical jump (VJ) height, endurance, oxidative stress, cell damage, muscle strength, and anaerobic and aerobic capacity were considered. Caffeine supplementation improved VJ height and agility while creatine, BCAA, HMB and mineral supplementation may improve anaerobic performance and muscle strength without a clear positive effect on VJ height, subject to a limited number of studies on each supplement. Creatine and BCAA effects were inconsistent concerning muscle damage.

Conclusions Among the investigated supplements, caffeine showed the most promising data to enhance physical performance and agility. NAC and GSE could improve antioxidant status. More research is needed to assess other supplements' effectiveness in volleyball players.

Protocol Registration https://doi.org/10.17605/OSF.IO/8RD9V.

✉ Ali Ali Redha
aa1249@exeter.ac.uk

[1] Research and Innovation Department, Instituto de Medicina Tropical y Salud Global, Universidad Iberoamericana, Francia Ave. 129, 10203 Santo Domingo, Dominican Republic

[2] Meshkat Sports Complex, Karaj, Alborz Province, Iran

[3] Arses Sports Complex, Karaj, Alborz Province, Iran

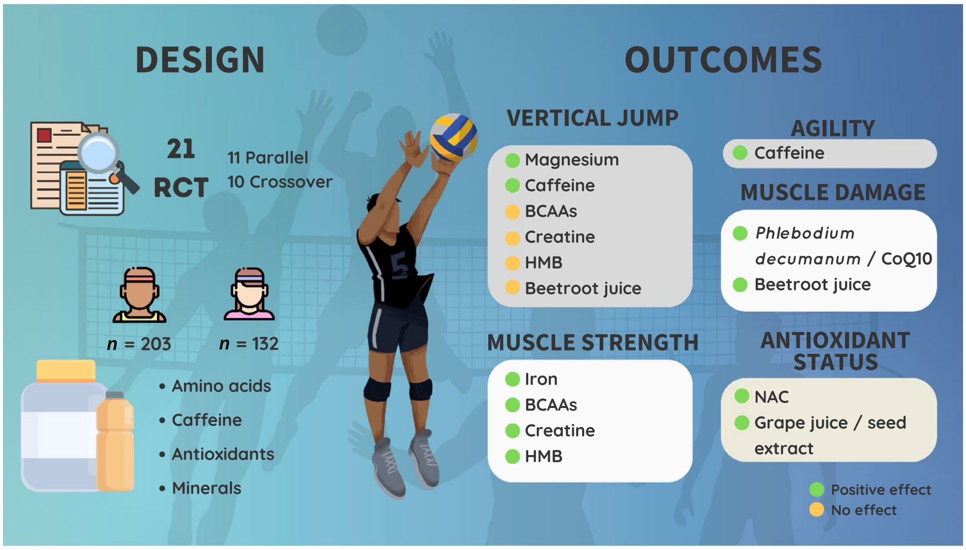
[4] The Department of Public Health and Sport Sciences, University of Exeter Medical School, Faculty of Health and Life Sciences, University of Exeter, Exeter EX1 2LU, UK

[5] Centre for Nutrition and Food Sciences, Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Brisbane, QLD 4072, Australia

[6] School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough LE11 3TU, UK

Published online: 12 July 2024

Graphical Abstract



Keywords Volleyball · Dietary supplements · Amino acids · Exercise performance · Oxidative stress · Caffeine

Introduction

Volleyball is a highly demanding sport that requires a unique combination of agility, speed, explosive power, muscular strength, coordination and endurance [15]. A regular training session includes muscular strength exercises such as squats, lunges, plyometric drills, cardiovascular training (running, shuttle sprints), skill (serving, passing, setting, spiking) and tactical drills development while a typical match consists of two teams aiming to score points and defend against incoming attacks in a best-of-five set format that may extend to several hours in a professional level [49]. For volleyball players, maximizing their performance and maintaining physical fitness is critical to compete at the highest level.

Although evidence suggests that volleyball matches increase inflammation and muscle damage to a lesser extent than other sports such as soccer and basketball [53], volleyball players have reported an increase in general stress, lack of energy, sport-specific stress (disturbed breaks, emotional exhaustion and injury scores), and a decrease in indicators of general recuperation including success, social recovery, physical recovery, self-efficacy and self-regulation [5]. This self-perception was accompanied by an increase in blood creatine kinase (CK), a marker of muscle damage, during the initial phases of the competitive season [5], while other studies report a decrease in antioxidant enzymes (catalase, glutathione reductase, and plasma total sulfhydryl groups) in the middle of the competitive season in both female and male volleyball players [8, 18], which could suggest a weakened antioxidant defence system.

While high-quality training sessions are necessary to optimise adaptations and performance, nutrition helps facilitate these adaptations and therefore competition performance [9]. Nutrition, and dietary supplements, play a key role in optimising volleyball players' performance [48]. Athletes should consume carbohydrates and fats for energy but also aim for a balance between energy expenditure and energy intake to ensure stable weight [9]. Athletes and fitness enthusiasts often turn to dietary supplements to enhance exercise performance and overall health; popular supplements include creatine, amino acids, beta-hydroxy-betamethylbutyrate (HMB), vitamins and minerals, omega-3 fatty acids, ginseng, and caffeine [9].

Supplements such as creatine are known for their role in rapid energy production during intense activities, potentially aiding recovery between high-intensity exercise bouts [54], while branched-chain amino acids (BCAAs), including leucine, isoleucine, and valine, are essential amino acids that may support muscle growth, exercise endurance and muscle protein preservation [47]. Some studies suggest BCAA supplementation may reduce fatigue, improve endurance and enhance lean body mass gains when combined with resistance training [43], although evidence supporting these findings is limited. Essential minerals such as iron, magnesium and zinc are typically included in a well-balanced diet and are known for their role in oxygen transportation, bone health, muscular function, cardiovascular well-being and several physiological processes [6, 16, 24, 33, 59]. Deficiencies can result from specific dietary choices and digestive disorders and some individuals may include them as dietary supplements [38].

Caffeine is a popular ergogenic aid that can boost alertness, wakefulness, and perceived energy levels [28]. Athletes often use caffeine as an ergogenic supplement to enhance endurance, strength, and concentration [28, 55]. However, caffeine may have adverse effects, abrupt cessation can lead to withdrawal symptoms like headaches and fatigue while consuming caffeine close to bedtime can disrupt sleep [4]. In some individuals, it may temporarily elevate heart rate and blood pressure [4]. Excessive consumption can also result in agitation, restlessness, stomach pain, and a rapid heart rate, and in extreme cases, caffeine overdose can have severe health consequences [4].

Collectively, there is evidence to suggest that volleyball is a physically demanding sport and therefore players may benefit from the use of dietary supplements to support training adaptations and performance. To date, however, there has been no attempt to systematically evaluate the effects of common dietary supplements on markers of training adaptation, performance and recovery. Therefore, this comprehensive systematic review aimed to examine the effects of different dietary supplementation strategies on volleyball players. Specifically, this study included studies that measured the effects of minerals, amino acids, caffeine, (poly)phenols and other antioxidants during training and competition on markers of training adaptations, exercise performance, and exercise recovery. The findings of this systematic review will help sports nutritionists, specifically those working with volleyball players, to utilise the use of different dietary supplements.

Method

The systematic review was conducted based on the recommendations of The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [44]. The protocol of this systematic review was registered at the Open Science Framework (https://doi.org/10.17605/OSF.IO/8RD9V).

Literature Search

A systematic database search of PubMed, Google Scholar, Cochrane, EBSCOhost, and Web of Science for randomized controlled trials examining the effects of dietary supplementation during endurance training on aerobic capacity, body composition, and exercise performance in volleyball players was conducted on 28th July 2023 and updated on 12nd May 2024. The search strategy was based on: ("supplement*" OR "dietary supplement*" OR "sport supplement*" OR "protein" OR "whey protein" OR "soy protein" OR "amino acids" OR "n-acetylcysteine" or "branched-chain amino acids" OR "BCAAs" OR "hydroxymethylbutyrate" OR "HMB" OR "creatine" OR "arginine" OR "citrulline malate" OR "caffeine" OR "polyphenols" OR "antioxidant" OR "fruit" OR "minerals" OR "iron" OR "magnesium" OR "vitamin" OR "coenzyme Q10" OR "probiotic" OR "prebiotic") AND ("volleyball"). The full research algorithm used for different databases is provided in the Supplementary File.

Study Selection

We included randomized controlled trials both crossover and parallel designed, that included volleyball players without known disease; and examined the efficacy of nutritional supplementation (minerals, amino acids, amino acid derivatives, caffeine, beetroot, (poly)phenols, and other antioxidants) during exercise training with an endurance training component; compared supplementation with control, including no supplement or placebo (e.g., non-nutritional supplement, or carbohydrate) and provided quantitative measurements of direct or indirect biomarkers or indicators of at least one of the following: aerobic capacity, anaerobic capacity, vertical jump height, muscle strength, muscle damage and inflammation and oxidant-antioxidant status. Exercise training had to be administered under identical conditions in each treatment comparison arm. Exclusion criteria included: multiple studies utilizing the same study sample, in which only one was included in the analysis unless additional information regarding study outcomes was provided; articles unavailable in English or Spanish; and retracted studies.

Data Extraction

Four reviewers independently selected studies from electronic databases and applied eligibility criteria (R.H., D.S., M.L., E.S.). After selected studies were pooled and duplicates were deleted, all authors checked decisions taken by the rest of the team, and disagreements were discussed with a fifth author (J.C.) if a solution or agreement was not possible. Extracted variables include population (n), age (mean), females (n), males (n), intervention group (n), type of intervention, dose, control group (n), and placebo specifications. Physical performance was primarily assessed by measuring vertical jump height (spike jump, block jump, countermovement jump), flight time, peak force during the concentric phase, peak power, the velocity at peak power, peak displacement, velocity and acceleration, and sprint capacity were included when available.

Biomarkers of muscle damage were measured as at least one of the following: serum creatine kinase (CK), lactate dehydrogenase (LDH), lactic acid, ammonia and perceived muscle soreness. Muscle strength was assessed by measuring hand grip force, squat strength or peak leg muscle power during the jump. To estimate oxidative/antioxidative status, one or more of the following variables were extracted: plasma glutathione (GSH), superoxide dismutase, catalase, malondialdehyde (MDA), total antioxidant capacity (TAC), nitric oxide (NO), lipid peroxidation, carbonyl levels, DNA damage index and sulfhydryl groups.

P-values from statistical tests were also extracted and are presented in the results section. Actual *P*-values are presented where possible, but thresholds (e.g., $P > 0.05$ or $P < 0.05$) are presented when the actual *P*-values were not presented.

Risk of *Bias* Assessment

Four reviewers (R.H., D.S., M.L. and E.S.) independently assessed the risk of bias within the included studies using Cochrane's revised risk of bias tool, RoB2 [56]. A fifth reviewer arbitrated when consensus was not found (J.C.). RoB 2 tool formulary includes preliminary considerations, signalling questions and five domains plus overall risk: (1) bias arising from randomization, (2) bias due to deviations from intended interventions, (3) bias due to missing outcome data, (4) bias in the measurement of the outcome, and (5) bias in the selection of reported result. Judgement options for each domain were "Low risk", "Some concerns" and "High risk". The decision to assign a level of risk was based on the RoB 2 algorithms, classifying the study as "low risk" when all domains were low risk, and "some concerns" or "high risk" when at least one domain was considered as such, for each case. For crossover studies, RoB 2 tool for crossover studies was used, which includes an additional domain (Domain “S”: bias resulting from the period and carry-over effect). results were printed through the web app *robvis* [39].

Results

Study Selection

The review identified 513 records by searching five databases. After removing duplicates, non-English or Spanish, and retracted studies, 151 articles were reviewed by four reviewers (R.H., D.S., M.L. and E.S.), 25 articles were sought for retrieval two were excluded: one was not available in full-text format, and the other did not have full-text in English or Spanish. Two eligible articles were identified by manual search. 23 articles were assessed for eligibility, of which four were excluded: two studies were not exclusively in volleyball players**;** one evaluated vitamin D in the regular diet rather than supplementation**;** and one study was excluded because the units of measurement for their outcomes were not specified**.** A total of 21 articles met the inclusion criteria and were included in the qualitative synthesis of the present systematic review **(**Fig. 1**).**

Characteristics of the Included Studies

The included studies were classified per type of dietary supplementation being evaluated, resulting in three categories: amino acids, minerals and plant-based supplements (caffeine, nitrates, (poly)phenols and other antioxidants). Some studies investigated more than one supplement and more than one outcome of interest. A total of seven parallel randomized controlled trials evaluated supplementation with different amino acids and derivatives including creatine ($n=4$) [1, 10, 31, 32], branched-chain amino acids (BCAA; $n=2$) [1, 35], hydroxy-methyl**-**butyrate ($n=1$) [48] and *n*-acetylcysteine (NAC) ($n=1$) [12]. One study evaluated both creatine and BCAA supplementation in different groups compared to a placebo [1]. Eight crossover randomized controlled trials in total were conducted to assess the effects of caffeine supplementation [13, 19, 30, 45, 46, 62]. Each study examined the impact of caffeine supplementation compared to a placebo. Four studies (crossover = 2; parallel = 2**)** evaluated supplementation with other plant-based supplements, including grape seed extract ($n=1$) [57], grape juice ($n=1$) [37], *Phlebodium decumanum* with coenzyme Q-10 ($n=1$) [20], and beetroot juice ($n=1$**)** [25]. Two studies evaluated the effects of mineral supplementation, including magnesium [51], and iron [40]. Detailed information about each included study can be found in Tables 1, 2, 3 and 4.

General Findings

Minerals

One study evaluated supplementation with magnesium (350 mg/day), reporting increased countermovement jump (CG = 40.6 ± 4.2 cm vs. EG = 42.5 ± 5.4 cm), and countermovement jump with arm swing (CG = 48.5 ± 4.8 cm vs. EG = 50.7 ± 7.2 cm), and significant decreases in lactate production in the experimental group ($P < 0.05$) [51]. Iron supplementation (325 mg/day) during the competitive season increased haemoglobin concentration, transferrin saturation index, serum iron, and serum ferritin compared to a control group, and increased performance for the clean and jerk (CG: + 5.1% ± 20.9% vs. EG: + 29.0% ± 21.3%), power clean (CG: − 5.8% ± 30.3% vs. EG: + 44.6% ± 56.6%), and total mean strength (CG: + 10.9% ± 3.2% vs. EG: + 26.2% ± 3.6%) in the experimental group (all $P < 0.05$) [40]. In summary, these findings suggest mineral supplementation has a positive effect on enhancing strength, countermovement jump, clean and jerk, and power clean.

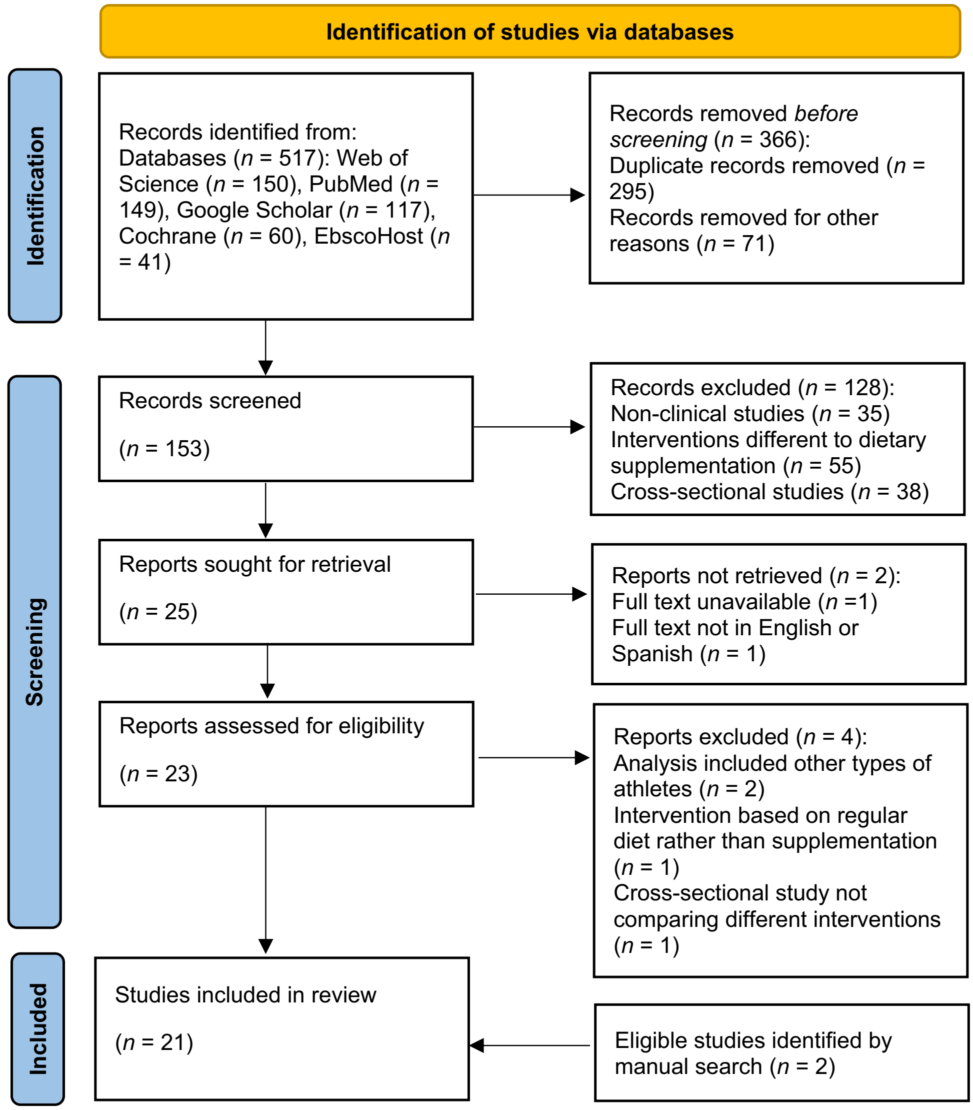


Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram

Amino acids and their derivatives

Six studies assessed the impact of different amino acids or amino acid derivatives (BCAAs, creatine, HMB and NAC) on vertical jump performance, and markers of training adaptation [1, 10, 31, 32, 35, 48] while one study evaluated antioxidant status (Table 2) [12]. In a study involving 12 male volleyball players, supplementation with creatine monohydrate powder in doses of 20 g/day (4 days), 10 g/day (2 days) and 5 g/day (22 days), improved repeated jump height by 1.9% compared to placebo, without affecting fatigue index ($P = 0.33$), however, 1 RM spike jump height was not significantly different from the placebo group ($P = 0.93$) [32]. Similarly, supplementation with 20 g of creatine (6 days) improved mean jump power (CG: 5.0 ± 0.8 W/kg vs. EG: 5.6 ± 0.1 W/kg) and endurance compared to baseline performance and placebo ($P < 0.05$) [31].

In another study, supplementation with, 0.3 g/kg/day of creatine and 1.2 g/kg/day of carbohydrate (loading phase, 7 d), and then 0.1 g/kg/day and 1.5 g/kg/day of carbohydrates (maintenance phase, 4 days), increased plasma creatine kinase concentration compared to placebo ($P < 0.001$). Jump height decreased after the injury protocol in the creatine group ($P < 0.022$) and returned to baseline after 24 h ($P = 0.238$), while the placebo group reported a significant increase in jump height after 72 h ($P = 0.008$); nevertheless, both jump height and power output were similar for creatine and placebo groups ($P = 0.849$; $P = 0.731$, respectively). Pain perception at 24, 48 and 72 h after muscle damage induction was significantly lower in creatine compared to placebo ($P = 0.001$; $P < 0.001$; $P = 0.011$, respectively) [10].

One study compared both supplementation with BCAA (12 g/day) and creatine-ginseng (0.99 g/kg/day creatine and 4.5 g/day ginseng) with placebo for 14 days and evaluated

Table 1 Summary of trials evaluating the effect of mineral supplementation in volleyball players on markers of training adaptations, antioxidant status, and exercise performance

Study and country	Supplement	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Mielgo-Ayuso et al. [40], Spain	Iron	RCT	F, NSE (Spain National Professional League). Mean age: 27 ± 6 years old	$n = 11$ Ferrous sulphate (325 mg/day; includes 105 mg of elementary iron)	$n = 11$ No intervention	11 weeks	Muscle strength: Bpress, military press, half-squat, power clean, clean and jerk, and pull-over	2 sessions: aerobic and resistance training	Oral iron supplementation prevents iron loss and enhances muscle strength in female volleyball players during the competitive season
Setaro et al. [51], Brazil	Magnesium	RCT, DB, PC	M, NSE (junior-youth and youth teams). SG mean age: 8 ± 1, CG mean age: 17 ± 2 years old	$n = 12$ Magnesium oxide (292 mg twice a day, capsules)	$n = 13$ Placebo: Maltodextrin 250 mg, capsules	4 weeks	VJ, CMJ, Lac and VO_{2max}	2 sessions, before and after the period of supplementation: aerobic and resistance training	Supplementation with magnesium correlated with a decrease in Lac production and significant increases in CMJ and CMJ with arm swing values

RCT randomised controlled trial, *DB* double-blind, *PC* placebo-controlled, *F* females, *M* males, *NSE* non-specified experience, *SG* supplemented group, *CG* control group, *VJ* vertical jump, *Bpress* bench press, *Lac* lactate, *CMJ* Countermovement jump, VO_{2max} maximal oxygen uptake

Table 2 Summary of trials evaluating the effect of amino acid supplementation in volleyball players on markers of training adaptations, antioxidant status and exercise performance

Study and country	Supplement	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Martín-Martíez et al. [35], Spain	BCAA	RCT, DB	M, ≥ 12 years of experience ($n = 12$), mean age: 24 ± 2 years old	$n = 6$ BCAA 7 g/day 3 days a week	$n = 6$ Placebo: water-melon-flavoured drink; no sugar added	7 days	VJ	Regular week of volleyball training, 3 training sessions x week + competitive game at the weekend. Plyometric training	ND in VJ
Ismail and Elbattawy [1], Egypt	BCAA; Creatine	RCT, PC	M, NSE ($n = 18$), mean age: 20 ± 1 years old	$n = 6$ BCAA 4 g × 3 times/day $n = 6$ Ginseng-Creatine 1.5 g and 0.33 g/kg per day	$n = 6$ Placebo: Apple juice 250 mL	18 days	Lower limb strength (Squad strength) Muscle damage (MS, CK, LDH)	2 sessions of resistance training; 3 min of rest between sets	MS increased above baseline in all groups at all time points. Peak soreness occurred in all groups 24 h after exercise ND in MS scores CK levels significantly increased in placebo group after intervention, BCAA and GCR had no significant increase
Lamontagne-Lacasse et al. [32], Canada	Creatine	RCT, DB, PC	M, NSE ($n = 8$), mean age: 22 ± 2 years old	$n = 4$ CrMs 20 g/day from day 1 to 4, 10 g/day from day 5 to 6 and 5 g/day from day 7 to 28	$n = 4$ Placebo: water (300 mL) containing; dextrose 20 g, sucrose 10 g, artificial flavour	28 days	VJ	2 sessions, before and after supplementation: aerobic training	ND in repeated VJ performance between groups pre- and post-supplementation
Chigachiaraguti et al. [10], Brazil	Creatine	RCT, DB, PC	M, under-21 years category ($n = 14$), mean age: 18 ± 0.3 years old	$n = 7$ CrMs 0.3—0.1 g/kg/day	$n = 7$ Placebo: Maltodextrin 0.5 g/kg/day	11 days	VJ and muscle damage (CK, LDH and MS perception)	Resistance and aerobic training	Creatine supplementation attenuated the perception of pain in volleyball players after the muscle damage protocol ND in VJ

Table 2 (continued)

Study and country	Supplement	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Kubota et al. [31], Japan	Creatine	RCT, DB, PC	M, 7–20 years of experience ($n = 21$). SG mean age: 23 ± 5, CG mean age: 23 ± 4 years old	$n = 11$ CrMs 20 g/day	$n = 10$ Placebo: Sports drink (protein 0.3 g, glucose 4.6 g, and minerals)	6 days	VJ and cycling power	5 sets of aerobic training	Jumping power of the initial five jumps was superior in participants supplemented with creatine monohydrate
Portal et al. [48], Israel	HMB	RCT, DB, PC	M ($n = 14$), F ($n = 14$), Israel Junior National Team. SG mean age: 16 ± 1, CG mean age: 16 ± 1 years old	$n = 14$ HMB 3 g/day	$n = 14$ Placebo: pills, non-specified composition	7 weeks	VJ, upper and lower limb strength	Resistance and aerobic training	HMB supplementation increased muscle mass, muscle strength and anaerobic properties ND in aerobic capacity or VJ
De Moraes et al. [12], Brazil	*N*-acetylcysteine [amino acid derivative]	RCT, PC	M, NSE ($n = 20$). SG mean age: 15 ± 1, CG mean age: 16 ± 1 years old	$n = 10$ *N*-acetylcysteine 1200 g/day	$n = 10$ Placebo: Maltodextrin 1200 mg/day	7 days	Oxidative stress (GPx1, SOD2, GSH3, FRAP4, TBARS5, and LOOH) and cellular damage (CK, AST, ALT and LDH)	Aerobic and resistance training	NAC increased GPx, SOD and TBARS. Protein carbonyls were lower in NAC SP ND in CK, AST, ALT and LDH

RCT randomised controlled trial, *DB* double blind, *PC* placebo controlled, *F* females, *M* males, *NSE* non-specified experience, *SG* supplemented group, *CG* control group, *VJ* vertical Jump, *LDH* lactate dehydrogenase, *CMJ* countermovement jump, *BCAA* branched-chain amino acid, *HMB* hydroxymethylbuthyrate, *CK* creatine kinase, *GCR* ginseng-creatine group, *CrMs* creatine monohydrate, *ND* no differences, *MS* muscle soreness, *GPx1* glutathione peroxidase, *SOD2* superoxide dismutase, *GSH3* reduced glutathione, *FRAP4* ferric reducing antioxidant power, *TBARS5* thiobarbituric acid reactive substances, *LOOH* lipid hydroperoxide, *AST* aspartate aminotransferase, *ALT* alanine aminotransferase

Table 3 Summary of trials evaluating the effect of antioxidant supplementation in volleyball players on markers of training adaptations, antioxidant status, and exercise performance

Study and country	Supplement	Type of study	Volleyball players	SG	CG	Study duration	Measured Outcomes	Exercise/training	Key findings
Taghizadeh et al. [57], Iran	Grape seed extract	RCT, DB, PC	F, NSE (Sports Club of Barij Essence, Iran). SG mean age: 20 ± 5, CG mean age: 22 ± 7 years old	$n = 20$ GSE 300 mg twice a day	$n = 20$ Placebo: pearls, twice a day	8 weeks	GSH, MDA, CPK, TAC, and NO serum levels	N/A	GSE increased GSH and decreased MDA levels ND in TAC, and serum lipid profile levels. After controlling for basal parameter NO concentrations were found to be significantly different between the two groups
Martins et al. [37], Brazil	Grape juice	RCT, DB, CO	M, NSE, National competitors. Mean age: 16 ± 0.6 years old	$n = 12$ 400 mL of grape juice (containing 66 g of carbohydrates)	$n = 12$ 400 mL of (poly) phenol-free beverage (containing 66 g of maltodextrin)	14 days	Oxidative stress (MDA, protein oxidation, DNA damage, sulfhydryl levels, SOD2, CAT), muscle damage (CK), muscle strength (handgrip strength), VJ	Aerobic training	SG reported a decrease in MDA levels, carbonyl levels, and DNA damage CG demonstrated increases in inflammation (IL-4 levels) and muscle damage (CK levels)
García Verazaluce et al. [20], Spain	*Phlebodium decumanun*, CoQ10	RCT, DB, PC	M, NSE, Volleyball Team of Universidad de Granada. Age range: 22 to 32 years old	$n = 10$ *Phlebodium decumanun* 1600 mg/day $n = 10$ CoQ 10 120 mg/day	$n = 10$ Placebo: Pills, non-specified composition	30 days	Cortisol, IL-6, Lac, and ammonia	Aerobic training	Lac, cortisol and IL-6 serum concentrations decreased in all groups The decrease in IL-6 and Lac levels was significantly greater in group two compared to both group 1 and control

Table 3 (continued)

Study and country	Supplement	Type of study	Volleyball players	SG	CG	Study duration	Measured Outcomes	Exercise/training	Key findings
Hemmatinafar et al. [25], Iran	Beetroot juice	RCT, DB, CO	F, semi-professional with ≥ 5 years of experience. Mean age: 26 ± 3 years old	*n* = 12 Beetroot juice 50 mL 4 times/day for 2 days	*n* = 12 Placebo: non-specified composition	30 days	Perceived MS (visual analogue scale), swelling score around the femur, PPT in the femur, VSFT, VJ, and wall-sit	Aerobic training	BRJ supplementation improved muscle endurance, thigh swelling and perceived MS 48 h after EIMD ND in pressure pain threshold, VSFT and VJ BRJ may have beneficial effects on some muscle recovery indicators

RCT randomised controlled trial, *DB* double-blind, *PC* placebo-controlled, *CO* crossover design, *F* females, *M* males, *NSE* non-specified experience, *SG* supplemented group, *CG* Control group, *GSE* grape seed extract, *VJ* vertical jump, *Lac* lactate, *BRJ* beetroot juice, *CoQ10* coenzyme Q10, *CK* creatine kinase, *ND* no differences, *MS* muscle soreness, GSH plasma glutathione, *MDA* malondialdehyde, *CPK* creatine phosphokinase, *TAC* total antioxidant capacity, *CAT* catalase, *SOD2* superoxide dismutase, *IL-4* interleukin 4, *IL-6* interleukin 6, *NO* nitric oxide, *PPT* pressure pain threshold, *VSFT* V-sit and reach flexibility test, *EIMD* exercise-induced muscle damage

exercise-induced muscle damage by measuring serum creatine kinase and lactate dehydrogenase and squat strength before and after testing. There was a significant increase in lactate dehydrogenase in the placebo group (563.75 ± 166.49 U/L) compared to both intervention groups (BCAA group: 142.17 ± 25.72 U/L; creatine group: 199.17 ± 81.04 U/L) ($P = 0.008$) and muscle strength recovery was superior in both groups 48 h after testing compared to placebo ($P = 0.02$) [1].

In another study, BCAA (7 g, three times per week) did not affect jump height compared to baseline or placebo from pre-test measurements to 50 h post-supplementation ($P > 0.05$) [35]. Supplementation with hydroxy-methyl-butyrate (3 g/day for 7 weeks) to a group of both females ($n = 14$) and males ($n = 15$) significantly increased strength in the bench press (CG: 1.19 ± 0.39 kg/kg BW vs. EG: 1.34 ± 0.40 kg/kg BW) and leg press (CG: 2.57 ± 0.67 kg/kg BW vs. EG: 2.81 ± 0.60 kg/kg BW), and aerobic capacity (peak power and mean power) (CG: 8.7 ± 0.9 kg BW vs. EG: 9.7 ± 1.0 kg BW) compared to placebo ($P < 0.05$). Supplementation did not affect vertical jump, anaerobic capacity, and fatigue index during anaerobic exercise ($P > 0.05$) [48].

Supplementation with NAC (1200 mg/day, 7 day) increased serum total glutathione compared to placebo in a study evaluating muscle damage and oxidative stress biomarkers: glutathione peroxidase (GPx), superoxide dismutase (SOD), reduced glutathione (GSH3), ferric reducing antioxidant power (FRAP4)**,** thiobarbituric acid reactive substances (TBARS), lipid hydroperoxide (LOOH), creatine kinase (CK), lactate dehydrogenase (LDH), alanine transaminase (ALT) and aspartate aminotransferase (AST) in 20 male professional volleyball players [12]. Higher GPx (CG: 3.2 ± 0.3 vs. 2.8 ± 0.3; EG: 3.0 ± 0.2 vs. 2.8 ± 0.4 U/mg of protein) and SOD (CG: 1.8 ± 0.1 vs. 1.4 ± 0.1; EG: 1.6 ± 0.2 vs. 1.4 ± 0.2 U/mg of protein) concentrations were observed in post-session 1 than in post-session 2 for both groups. Protein carbonyls were lower in the NAC group compared to placebo. Alternatively, a time effect was found for TBARS, with lower values reported in pre-session 1 than in pre-session 2 ($P < 0.05$). No significant changes were found in the other markers measured ($P > 0.05$) [12].

In summary, while some studies showed similar results in jump height and power between groups, and no effects on vertical jump, anaerobic capacity, and fatigue index during anaerobic exercise; overall, amino acid supplementation seems to have improved strength (as measured by repeated jump height, mean jump power, bench press, and leg press) and increased aerobic capacity and endurance. Additionally, pain perception was significantly lower in some experimental groups compared to the placebo. Notably, in some studies, there was a significant increase in lactate dehydrogenase in the placebo group, while both intervention groups showed superior muscle strength recovery. On the other hand, NAC

Table 4 Summary of trials evaluating the effect of caffeine supplementation in volleyball players on markers of training adaptations, antioxidant status, and exercise performance

Study and country	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Zbinden-Foncea et al. [62], Chile	RCT, DB, CO	M, with at least 6 years of experience ($n = 10$). Mean age: 19 ± 2 years old	$n = 10$ Anhydrous caffeine 5 mg/kg (capsule)	$n = 10$ Placebo: Dextrose capsule	1 week	VJ	2 sessions: aerobic training	Caffeine increased CMJ performance metrics: concentric peak force and peak power compared to placebo trial Velocity at peak power, force developed at peak power, and VJ height were higher when compared to placebo Flight time was higher in placebo trial
Del Coso et al. [13], Spain	RCT, DB, CO	M, ≥ 4 years of experience ($n = 15$). Mean age: 22 ± 7 years old	$n = 15$ Powdered caffeine-containing energy drink dissolved in 250 mL of tap water 3 mg/kg	$n = 15$ Placebo: Non-caffeinated energy drink	1 week	Handgrip force, pike-ball velocity, VJ, and time to complete the Agility *t*-Test	Aerobic training	Caffeinated energy drink increased handgrip force in both hands, maximal velocity of the ball during the standing spike test and jump height and peak leg-muscle power during SJ and CMJ tests Caffeinated energy drink increased the mean jump height The caffeinated energy drink also reduced the time to complete the agility T-test
Pfeifer et al. [46], The United States	RCT, DB, CO	F, NSE ($n = 8$). Age range: 18–22 years old	$n = 8$ Caffeine 1.39 mg/kg + carbohydrates 1.34 g/kg	$n = 8$ Placebo: Non-nutritive gel flavoured with sugar alcohol $n = 8$ No intervention	3 weeks	VJ, agility (time to perform three-cone drill), sprint speed (running-based anaerobic sprint test	Aerobic training	ND between conditions on the dependent variables of VJ, agility, and sprint speed
Filip-Stachnik et al. [19], Poland	RCT, DB, CO	F, with a mean experience of 10 years ($n = 12$). Mean age: 20 ± 2 years old	$n = 12$ Caffeinated chewing gum ~ 6.4 mg/kg	$n = 12$ Placebo (non-caffeinated chewing gum)	72 h	VJ and game assessment	2 sessions: aerobic training	Caffeinated chewing gum increased jump attack height and jump attack performance in comparison to the placebo ND in BJ height

Table 4 (continued)

Study and country	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Pérez-López et al. [45], Spain	RCT, DB, CO	F, ≥ 6 years of experience ($n=13$). Mean age: 25 ± 5 years old	$n=13$ Caffeine, energy drink powder, 3 mg/kg	$n=13$ Placebo: Non-caffeinated energy drink	1 week	Handgrip force, VJ, spike ball velocity, agility *t*-test	2 sessions: aerobic and resistance training	Caffeinated energy drink increased the ball velocity in the standing spike and the jumping and the jump height in the squat, countermovement, spike jump, and block jump The drink decreased the time needed to complete the agility *t*-test During the game, the volleyball actions categorized as successful were more frequent with the caffeinated energy drink, whereas imprecise actions decreased when compared with the placebo drink
Kaszuba et al. [30], Poland	RCT, DB, CO	M ($n=9$) and F ($n=3$), ≥ 5 years of experience. Mean age: 23 ± 3 years old	$n=12$ Caffeinated chewing gum ~ 3.2 mg/kg	$n=12$ Placebo: Non-caffeinated chewing gum	72 h	VJ, straight sprints (5 to 10 min), agility *t*-test, an attack and service speed test, spike and serve accuracy test	Aerobic training	A caffeine-containing chewing gum effectively improved the attack's accuracy in volleyball players ND in jumping, running, and other skill-based volleyball tests
Nemati et al. [41], Iran	RCT, DB, CO	M, 5 years of experience ($n=15$). Mean age: 20.8 ± 1 years old	$n=15$ Caffeine (capsules) Group 1: 3 mg/kg Group 2: 6 mg/kg	$n=15$ Starch, capsule	3 weeks	Handgrip force, VJ, Upper body explosive power, attack skill, service skill, agility *t*-test	3 sessions: aerobic and resistance training	High-dose caffeine capsules (G2) improved VJ and serving skills compared to lower doses and placebo G2 improved agility compared to placebo G1 and G2 improved attacking skills when compared to placebo ND in handgrip force

Table 4 (continued)

Study and country	Type of study	Volleyball players	SG	CG	Study duration	Measured outcomes	Exercise/training	Key findings
Siquier-Coll et al. [52], Spain	RCT, DB, CO	F, NSE, Spanish Women's Super-league 2 ($n=8$). Age interval: 17–25 years old	$n=8$ Anhydrous caffeine powder, 5 mg/kg with maltodextrin-based beverage	$n=8$ Maltodextrin-based beverage	3 weeks	Handgrip force, VJ, Agility *t*-test	3 sessions: aerobic and resistance training	Caffeinated beverage increased VJ height and handgrip compared to placebo ND in agility

RCT randomised controlled trial, *DB* double-blind, *CO* crossover design, *F* females, *M* males, *NSE* non-specified experience, *SG* supplemented group, *CG* control Group, *VJ* vertical Jump, *CMJ* countermovement jump, *BJ* block jump, *SJ* spike jump, *ND* no differences, *G1* Group 1, *G2* Group 2

supplementation was found to increase serum total glutathione levels and showed lower levels of protein carbonyls in the NAC group compared to the placebo.

Antioxidants and Nitrates

Four studies investigated the impact of different plant-based dietary supplements, grape seed extract, grape seed juice, *P. decumanum* combined with coenzyme Q-10 and beetroot juice on markers of oxidative/antioxidant status, muscle damage and physical performance (Table 3) [20, 25, 37, 57]. One randomized clinical trial evaluated the effects of grape seed extract (GSE) supplementation (600 mg/day) on biomarkers of oxidative stress in a group of 40 female volleyball athletes [57]. There was a significant rise in plasma glutathione (GSH) level (changes from baseline in the GSE group: $+265.5 \pm 344.2$ vs. in the placebo group: $+2.2 \pm 378.2$ µmol/L, $P=0.02$), as well as a significant decrease in the MDA level (-1.4 ± 2.0 vs. -0.2 ± 1.2 µmol/L, $P=0.01$). Supplementation with GSE had no significant effects on creatine phosphokinase (CPK), TAC, NO, plasma glucose, and lipid concentrations.

A crossover study assessed the effects of supplementation with grape juice (GJ) for 2 weeks on markers of oxidative stress, inflammation, CK, muscle strength, and muscle power in 12 male volleyball players. The sample was divided into an experimental group (400 mL of grape juice) and a placebo group [400 mL of (poly)phenol-free beverage]. In the GJ condition, there was a significant reduction in lipid peroxidation (MDA Levels) by 50% ($P<0.05$), as well as a decrease in carbonyl levels by 19% ($P<0.01$) and DNA damage by ~ 15% ($P<0.05$). However, the activity of sulfhydryl groups and antioxidant enzymes (SOD and CAT) did not change ($P>0.05$) and muscle strength (hand grip test) remained unaffected. A 4% increase ($P<0.001$) in vertical jump was also reported. In the placebo condition, there was an increase in IL-4 by 14% ($P=0.03$) and CK by 31% ($P<0.01$), which was not observed in the GJ group [37].

Supplementation with *P. decumanum* and coenzyme Q-10 for 4 weeks improved the basal endocrine-metabolic and immunological profile of 30 male professional volleyball players. The sample was divided into an experimental group 1 (EG1, 1.6 g of *P. decumanum*), an experimental group 2 (EG2, 1.6 g of *P. decumanum* and 120 mg of coenzyme Q-10) and a control group [37]. There was a significant decrease ($P<0.05$) in cortisol, interleukin 6, lactic acid, and ammonia compared to their pre-intervention levels. However, when comparing the results across the groups, supplementation (EG1 and EG2) reported a greater decrease ($P<0.05$) in the biomarkers compared to placebo. Furthermore, the group that received both supplements (GE2) experienced significantly ($P<0.05$) lower IL-6 and lactate levels in the post-test compared to other groups.

After evaluating the pre-test—post-test intragroup difference using the Wilcoxon test, it was observed that the training program decreased basal levels of cortisol, IL-6, lactic acid, and ammonium levels, independently of the supplements ($P < 0.05$) [20].

Supplementation with beetroot juice (BRJ; 200 mL/day) for 2 days after high-load training in female volleyball athletes decreased thigh swelling and perceived muscle soreness (estimated with a visual analogue scale; $P < 0.05$). However, beetroot juice supplementation did not change pressure pain threshold or vertical jump height, when compared to placebo ($P > 0.05$) [25].

In summary, findings reveal compelling evidence supporting the efficacy of GJ supplementation in elevating plasma GSH levels and reducing lipid peroxidation, as evidenced by decreased malondialdehyde levels. However, no significant effects were observed on CPK, TAC, NO, plasma glucose, and lipid concentrations. Furthermore, supplementation with *P. decumanum* and coenzyme Q-10 was associated with a significant reduction in cortisol, IL-6, lactic acid, and ammonia levels. Additionally, beetroot juice supplementation demonstrated a notable decrease in thigh swelling.

Caffeine

Eight studies evaluated the impact of caffeine supplementation on the physical performance of volleyball players (Table 4) [13, 19, 30, 41, 45, 46, 52, 62]. Supplementation with anhydrous caffeine-containing capsules (5 mg/kg, 60 min before training) in ten male volleyball players increased countermovement jump performance by improving flight time, peak force during concentric phase, peak power, velocity at peak power, force developed at peak power and peak displacement, velocity and acceleration with a *P*-value of ($P < 0.05$) [62].

Similarly, a study followed the correlation of low-dose (3 mg/kg, 60 min before training; Group 1), high-dose (6 mg/kg, 60 min before training; Group 2) caffeine capsules and placebo with handgrip force, vertical jump, upper body explosive power, attack skill, service skill and agility in male volleyball players. Both low-dose (MD = 2.26, $P < 0.05$, 95% CI [1.22–3.31]) and high-dose (MD = 2.8, $P = 0.001$, 95% CI [1.11–4.48]) caffeine capsules improved attacking skills when compared to placebo. High-dose caffeine capsules increased vertical height and serving skills when compared to lower dose and placebo (MD = 3.33, $P < 0.05$, 95CI [1.93–4.72]; MD = 4.26, $P < 0.05$, 95% CI [3.01–5.52], respectively) [41]

Caffeine-containing energy drinks were assessed in two studies [13, 45]**.** Energy drinks containing caffeine in a dose of 3 mg/kg ingested 60 min before training increased jump height (CG: 31.1 ± 4.3 cm vs. EG: 32.7 ± 4.2 cm) (spike, block, squat and countermovement variations) as well as hand grip force in both right (CG: 404 ± 88 N vs. EG: 439 ± 66 N) and left (CG: 391 ± 70 N vs. EG: 420 ± 72 N), maximal velocity of the ball (CG: 73 ± 9 vs. EG: 75 ± 10 km/h), and peak leg muscle power during jumping ($P < 0.05$) [13]. A decrease in time to complete the agility test was reported in both studies. In one study, game performance was superior in a simulated game (positive game actions increased, negative game actions decreased) compared to placebo ($P < 0.001$) [45].

Supplementation with caffeine powder in a maltodextrin-based beverage (5 mg/kg, 60 min before training) in a cohort of eight female volleyball players resulted in increased vertical jump height [F (1.7) = 5.97, $P = 0.04$, $\eta^2 = 0.46$] and handgrip force in the dominant hand [F (2.14) = 9.56, $P = 0.004$, $\eta^2 = 0.65$] when compared to placebo. No significant difference was observed in the agility *t*-test [52].

The impact of caffeinated chewing gum (~3.4 to ~6.4 mg/kg, 15 min before training) was evaluated in two studies [19, 30]. Attack jump height was increased (CG: 46.3 ± 7.6 cm vs. EG: 47.5 ± 6.9 cm) [19] as well as the attack's accuracy (CG: 15 ± 4 points vs. EG: 18 ± 3 points) ($P < 0.05$), in one study [30], but no changes were observed in block jump, countermovement jump, squat jump, sprint time, time to complete agility *t*-test nor overall performance during a simulated game ($P > 0.05$) [19, 30]. Caffeinated gel (1.39 mg/kg) administered immediately before training in eight female volleyball players did not significantly increase vertical jump height, agility or sprint capacity ($P > 0.05$) compared to placebo [46].

In summary, these findings suggest caffeine supplementation have a positive effect on vertical jump height, agility as defined by time to complete an agility *t*-test and attacking skills. The magnitude of these correlations is stronger in studies giving doses of ~ 3 mg/kg and higher.

Risk of Bias in Studies

The risk of bias analysis concluded that 81% (17/21) of the studies had an overall low risk (Fig. 2). Bias arising from the randomization process and deviations from the intended intervention represented the main concern in 4 studies [1, 16, 17, 46], as they did not specify the process of randomization, or the study was not double-blind. Bias due to missing outcome data and in the selection of reported results was low for all the studies. One study [17] was classified as high risk of bias due to concerns in measurements of the outcome, specific units of measurement in all quantitative results were not provided, hence the findings could not be interpreted and compared to other studies.

Discussion

The main findings of this review are that supplementation with some dietary supplements enhanced markers of performance and recovery in volleyball players, but the overall number of studies for each supplement was small. The summary of the effect of different supplements on volleyball players is illustrated in Fig. 3. The most studied supplements were creatine and caffeine. The effects of creatine and BCAA were inconsistent, but caffeine consumption before training and volleyball matches improved aspects of physical performance, muscular strength and agility in most studies. There was also evidence that NAC and grape seed extract consumption modulated antioxidant status and reduced oxidative stress markers post-exercise, while beetroot juice reduced muscle soreness. Individual studies also suggested some benefits for various outcomes after iron, magnesium and HMB supplementation. However, due to the limited number of studies on these supplements, definitive conclusions on their effectiveness cannot be drawn. Collectively, this review suggests that some dietary supplements, notably caffeine, could support performance in volleyball players, but the limited number of studies for most supplements limits the applicability of the findings.

Minerals

Some studies suggest that certain mineral supplements have an ergogenic effect on athlete performance [40, 51]. However, studies examining the effects of mineral supplements on performance in volleyball players were scarce. In a study, 4 weeks of magnesium supplementation improved countermovement jump height but did not affect aerobic and anaerobic performance [51]. The mechanisms to explain the improvements in CMJ performance in this study were not clear. In addition, 11 weeks of iron supplementation prevented a decline in the haematological parameters (haemoglobin, transferrin saturation index, serum iron, and serum ferritin) and increased total mean strength in female volleyball athletes [40]. Collectively, our review suggests that iron may increase muscle strength, and magnesium supplementation may improve jump height, but only one study was available for each supplement, limiting the translation of the findings.

Amino acids and their derivatives

The current systematic review evaluated eight studies evaluating different types of amino acid supplements and their impact on different parameters of physical performance in volleyball players [1, 10, 12, 31, 32, 35, 48]. Overall, these studies showed that amino acids and amino acid derivatives may have a positive impact on the physical performance of volleyball players, with different grades of impact for each outcome.

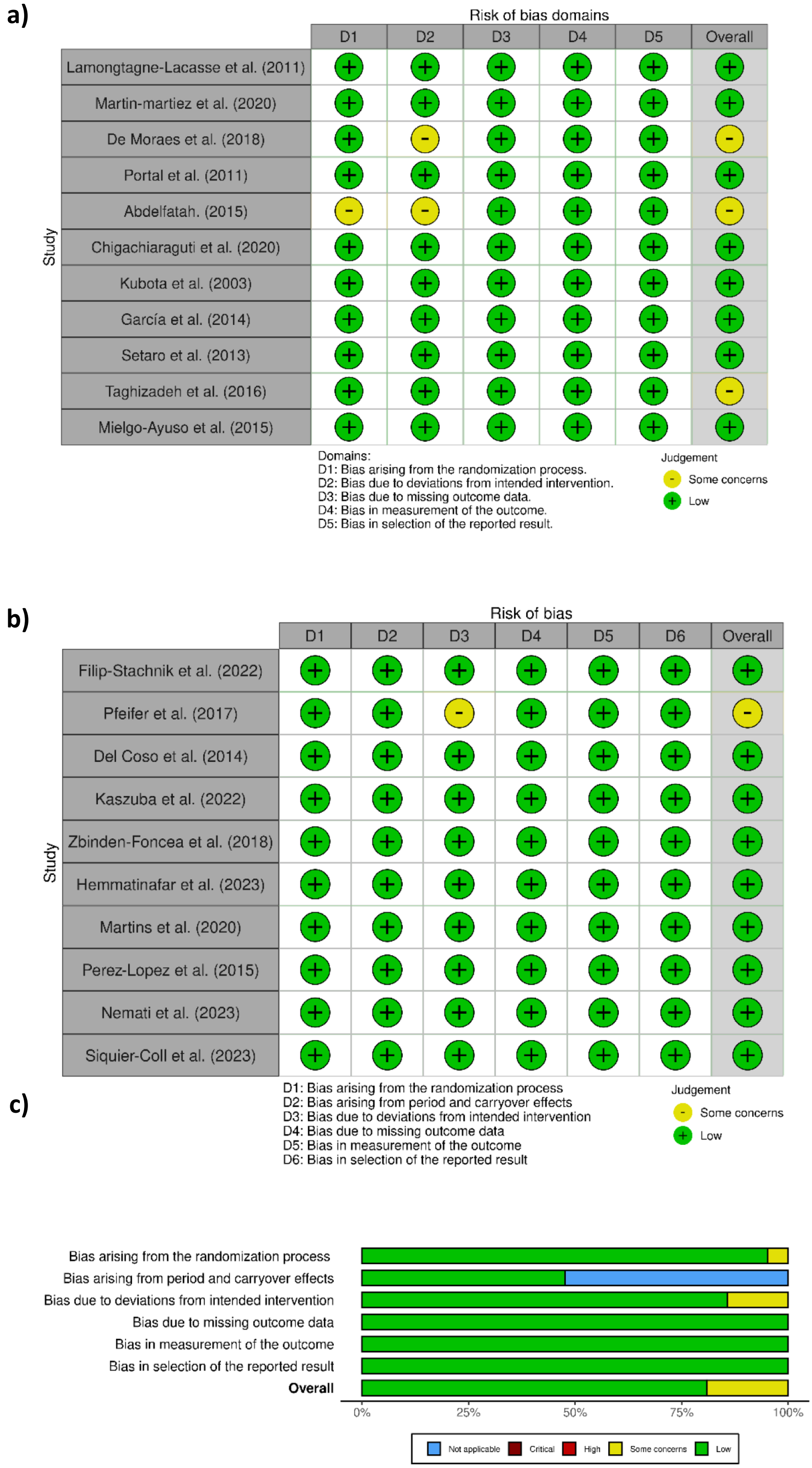
Mechanistically, studies suggest that exercise coupled with adequate amino acid intake can influence skeletal muscle protein synthesis and thus the development and maintenance of lean muscle mass, which, in turn, can enhance muscle strength and power [15, 34]. The findings from the included studies suggest that supplementation with creatine, BCAA and HMB does not increase vertical jump height capacity compared to baseline, but increases vertical jump endurance, anaerobic performance, and upper and lower limb strength [1, 10, 32, 35]. Supplementation with a high dosage of BCAA (12 g/day, 18 days) attenuated the decrease in squat strength 48 h after strength testing compared to placebo It has been suggested that BCAAs may facilitate post-exercise recovery by reducing muscle discomfort and accelerating muscle tissue repair and development [47], but this effect was not consistently shown in the studies [35].

HMB is a compound that results from the metabolism of the essential amino acid leucine and is frequently used as a nutritional supplement among athletes [43]. We only found one study with this supplement in volleyball players, which evaluated the impact of 3 g/day of HMB during a 7-week supplementation period with a sample including both males ($n = 15$) and females ($n = 14$). They reported a significant increase in anaerobic performance determined by peak power output and mean power output during a run-up test in a cycle ergometer. It also led to an increase in fat-free mass (FFM) compared to placebo and an increase in bench press and leg press strength as well. The mechanisms to explain these effects are not clear though, a rodent study suggested that HMB can reduce protein breakdown [21], but evidence in humans is lacking. Many studies have found no performance or body composition benefits of HMB intake and generally do not suggest HMB is an efficacious ergogenic aid [27, 58].

In addition to their role in protein synthesis, some amino acids act as precursors of compounds with antioxidant properties. Intense and demanding exercise can produce excessive free radicals, which can contribute to oxidative stress and cellular damage [12]. Supplementation with specific amino acids or compounds with antioxidant effects can help counteract the adverse effects of oxidative stress by increasing the body's antioxidant capacity. NAC is an antioxidant that can attenuate fatigue during prolonged exercise, possibly by helping to maintain antioxidant capacity and therefore muscle force production [2, 12]. This is particularly relevant for volleyball players, as oxidative stress can affect recovery and contribute to muscle fatigue [2].

One study administered NAC for 7 days, which increased serum glutathione compared to placebo [12]. However, it is

Fig. 2 Assessment of bias of the randomized studies: **a** Traffic light plot for parallel designed RCTs, **b** traffic light plot for cross-over designed RCTs, **c** summary plot



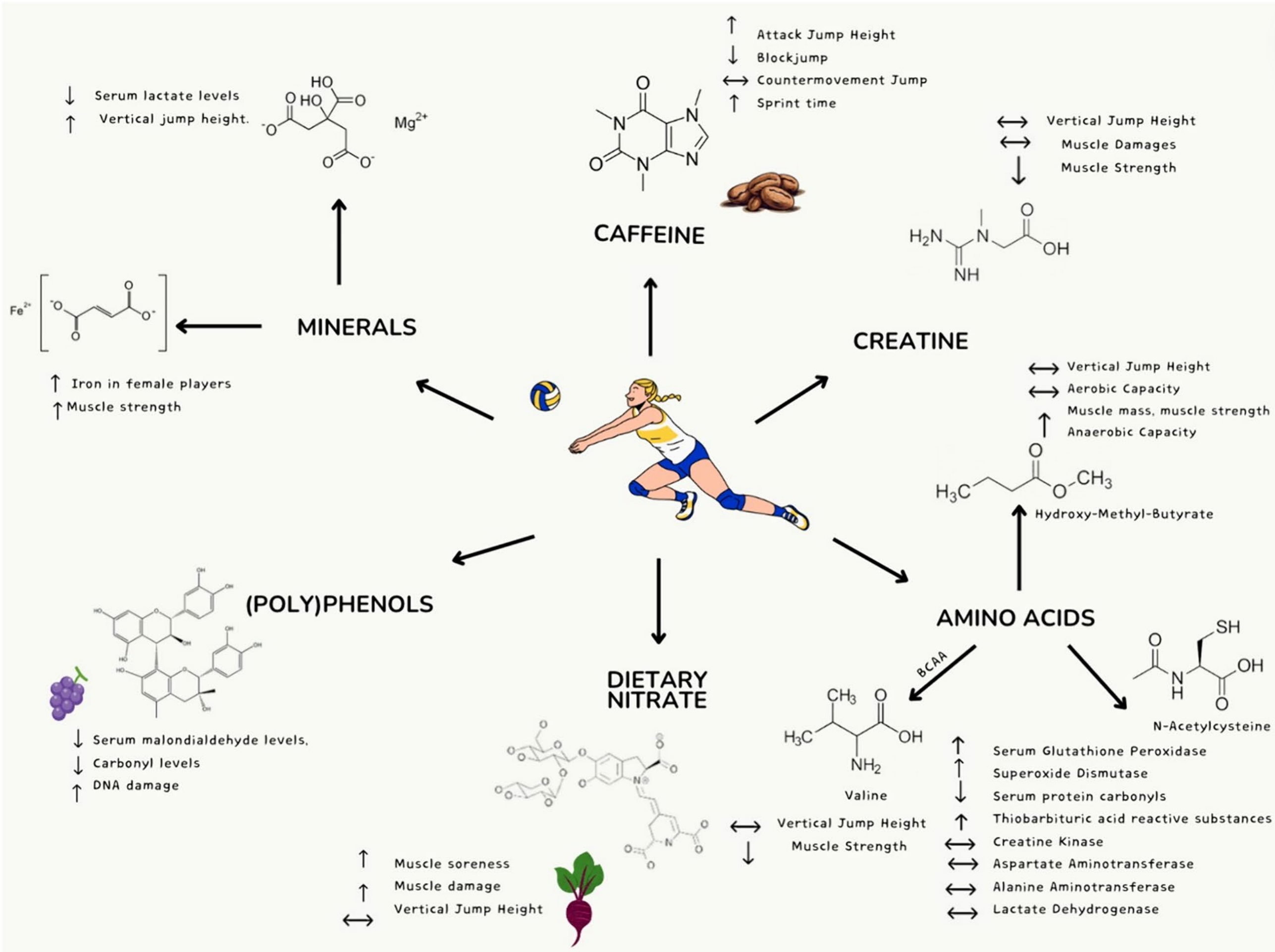


Fig. 3 Summary of the effects of different dietary supplements on volleyball players. (Key: ↑ positive/beneficial effect, ↔ no effect, and ↓ negative/unfavourable effect)

difficult to determine if this effect was due to an upregulation of antioxidants, or greater oxidative stress. Similarly, a study demonstrates that pretreatment with vitamin E (300 mg/day), vitamin C (200 mg/day), zinc gluconate (45 mg/day) and selenium (100 µg/day) for six weeks in female volleyball athletes prevents depletion of total plasma antioxidant potential and protein oxidation accompanying exercise, measured by estimating serum levels of MDA [36]. Although protein carbonyls were greater in the placebo group than in the NAC group, indicating that oxidative stress was lowered by NAC, TBARS were higher in both the NAC and placebo groups after pre-session 1, indicating that lipid oxidation s increased between the first and second sessions in both groups [12]. This is consistent with a previous systematic review that showed NAC significantly reduced MDA levels, especially with higher doses (>1000 mg/day and longer duration of intake for more than 4 weeks [29].

Antioxidants and Nitrates

(Poly)phenols, chemical compounds with antioxidant capacity, help defend against oxidative stress caused by excess ROS production [7, 37, 61]. Foods like grapes that contain high levels of (poly)phenols help prevent the oxidation of essential molecules such as proteins and DNA [7, 37]. Furthermore, the effects of (poly)phenols may be due to a combination of several different mechanisms, including modulation of the expression of endogenous antioxidant systems, direct scavenging of free radicals, and promotion of DNA repair [3, 14, 57].

Administration of 600 mg/day of grape seed extract increased plasma GSH, decreased MDA and prevented an increase in CK levels in female volleyball players after 8 weeks of supplementation [57]. However, the training load imposed on the athletes during the 8 weeks was not specified in the study. Another study found that consumption of 400 mL of grape juice for 14 days decreased indicators of oxidative stress and lipid damage, presenting a significant decrease of 50% in MDA levels [37]. Grape juice also decreased DNA damage, and presented lower carbonyl levels, indicating less protein damage [37]. The mechanisms to explain these effects are not entirely clear, but grapes are rich in flavonoids, which have antioxidant and anti-inflammatory effects [50]. Thus, it is possible that the (poly)phenol-rich grape-based supplements in these studies attenuated oxidative stress in these athletes.

Co-supplementation with *P. decumanum* and coenzyme Q-10 (Ubiquinone) during a 4-week training program (5 days a week, 3 h per session) decreased serum cortisol, interleukin-6, lactic acid and ammonia concentrations groups [20]. Supplementation with both coenzyme Q-10 and *P. decumanum* showed a greater decrease in post-test IL-6 and lactic acid levels compared to the other groups [20]. The effects of *P. decumanum* are likely due to its (poly)phenol constituents, which have been shown to decrease exercise-induced oxidative stress and decrease inflammatory markers [14].

Nitrate-rich foods have been studied for their impact on oxygen consumption and recent studies suggest they enhance exercise performance by modulating mitochondrial ATP synthesis, increasing the efficiency of muscle contractions and oxidative phosphorylation [42]. In this systematic review, we found only one study examining the effects of nitrate-rich beetroot juice in volleyball players, and they reported reduced thigh swelling and perceived muscle soreness in athletes [[25]. Several previous studies have shown that beetroot juice may attenuate markers of muscle damage following exercise [29], likely owing to the betalain compounds, which have antioxidant and anti-inflammatory effects [11].

Caffeine

The current evidence suggests that the intake of caffeine-containing dietary supplements has a positive impact on volleyball players' performance. Caffeine is an adenosine receptor antagonist, thus stimulating the central nervous system, increasing alertness and reducing effort perception during exercise [28, 55]—such effects may enhance high-intensity exercise performance [23]. In this review, we found that supplementation with caffeine increased vertical jump height, peak power, and velocity at peak power in volleyball players [13, 19, 30, 45, 62]. It also increased agility, determined by a decrease in the time to complete the agility *t*-test [13, 45].

The aforesaid beneficial effects of caffeine were observed in females [19, 45], males [13, 62], and mixed-sex studies [30]. However, these effects were not observed in a study using a low dose of caffeine (1.39 mg/kg); where vertical jump height, agility and sprint capacity were unchanged compared to placebo [46]. However, the absence of effects may not only be solely related to the dose, but also due to the form of delivery (caffeinated gel) compared to the energy drinks and caffeinated chewing gum used in other studies. Furthermore, beneficial performance effects were more evident in studies evaluating caffeine-containing energy drinks [13, 45] and caffeine capsules [62] compared to studies evaluating caffeinated chewing gum [19, 30], despite of chewing gum containing high doses of caffeine [30] and evidence suggesting quicker absorption through oral mucosa of caffeine delivered via chewing gum [60], the inclusion of other substances in energy drinks besides of caffeine may exert as aconfusing bias for this specific scenario. Timing of intake before training may also impact physical performance. In the studies reporting positive effects of caffeine on physical performance, supplements were ingested 15 to 60 min before training [13, 19, 30, 45, 62] instead of immediately before training [46]. Caffeine is rapidly absorbed in humans,however, it takes between 15 to 120 min after ingestion to reach peak plasma concentrations, depending on gastric emptying time and the presence of other dietary constituents [26]. Collectively, the beneficial effects reported in most studies suggest that caffeine supplementation may enhance performance in volleyball athletes.

Current limitations

Certain limitations need to be acknowledged. Firstly, the findings of this review are based on results from a limited number of articles, that measured a wide range of dietary supplements and outcomes. Thus, the results for any individual supplements and their effects on specific markers of performance or recovery should be interpreted cautiously. The included studies also had limitations that affect the conclusions that can be drawn from this review. Dietary control and/or habitual dietary intake were not reported by all of the included studies; some included counselling by dietitians or nutritionists [1, 19, 35], and others included self-reporting by participants [12, 48, 62]. One study on supplementation with creatine did not explicitly disclaim information about diet control or food recording of the participants [31]. Thus, it is possible that the players' habitual dietary intake influenced the findings in some of the included studies. Additionally, many studies provided limited information on any exercise controls in the studies. Many of the studies had low sample sizes and were not likely adequately powered to detect smaller statistically significant effects. Many of the outcomes in the included studies may also not reflect the condition/state being examined,for example, oxidative stress markers such as TBARS and TAC are unspecific and not recommended [22]. We decided to report these indicators since we only included one study about the effects of N-acetylcysteine on cellular damage and oxidative stress. Finally, in some instances, studies provided limited information on the content of the interventions and their bioavailability, especially for (poly)phenol supplements.

Conclusions

In conclusion, several different dietary supplements have been examined for their potential to improve performance recovery in volleyball players. Caffeine and creatine were the most studied supplements, and both found potential benefits on markers of exercise performance, albeit the results were more inconsistent for creatine**.** There was also evidence from individual studies that NAC, HMB, BCAA, iron, beetroot juice and (poly)phenol-rich supplements could modulate performance or other markers, but the limited number of studies precludes any definitive recommendations. Future studies should examine whether the aforesaid supplements could enhance markers of exercise performance and recovery in volleyball players, where possible in randomised controlled trials that include adequate dietary controls, sufficient sample sizes, and the gold-standard measures for the outcomes of interest.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s42978-024-00297-6.

Acknowledgements The authors would like to thank the Cambridge University ReachSci Society and Prof Joanna Bowtell (University of Exeter) for their support and assistance. This project was an outcome of the Mini-PhD Programme 2023: Food Science & Nutrition.

Author Contributions Conceptualisation: RZ and AAR. Methodology: RZ and AAR. Investigation, data curation, formal analysis, and Writing—Original Draft: REHZ, ML, DS, ESA, and JLCM. Writing—Review & Editing: AAR, RZ, and TC. Project administration: AAR, and JLCM. Supervision: JLCM, AAR, and TC.

Funding Not applicable.

Data availability Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Declarations

Conflict of Interest All authors declare no conflict of interest. For the purpose of open access, the author, Ali Ali Redha, has applied a ‘Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising’.

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

References

1. Abdelfatah Ismail KE. Effect of branched-chain amino acids and ginseng-creatine supplementation on delayed onset muscle soreness and muscle damage in volleyball players. Assiut J Sport Sci Art. 2015;115(1):309–26. https://doi.org/10.21608/AJSSA.2015.70848.
2. Alduraywish AA. Cardiorespiratory and metabolic fitness indicators in novice volleyball trainees: effect of 1-week antioxidant supplementation with *N*-acetyl-cysteine/zinc/vitamin C. J Int Med Res. 2021;49:030006052110671. https://doi.org/10.1177/03000605211067125.
3. Ali Redha A, Siddiqui SA, Zare R, Spadaccini D, Guazzotti S, Feng X, Bahmid NA, Wu YS, Ozeer FZ, Aluko RE. Blackcurrants: a nutrient-rich source for the development of functional foods for improved athletic performance. Food Rev. Int. 2024;40(1):135–57. https://doi.org/10.1080/87559129.2022.2162076.
4. Alstadhaug KB, Ofte HK, Müller KI, Andreou AP. Sudden caffeine withdrawal triggers migraine—a randomized controlled trial. Front Neurol. 2020;11:562486. https://doi.org/10.3389/fneur.2020.01002.
5. Berriel GP, Costa RR, da Silva ES, Schons P, de Vargas GD, Peyré-Tartaruga LA, Kruel LF. Stress and recovery perception, creatine kinase levels, and performance parameters of male volleyball athletes in a preseason for a championship. Sports Med Open. 2020;6(1):26. https://doi.org/10.1186/s40798-020-00255-w.
6. Bloor SR, Schutte R, Hobson AR. Oral iron supplementation—gastrointestinal side effects and the impact on the gut microbiota. Microbiol Res (Pavia). 2021;12:491–502.
7. Bravo L. Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. Nutr Rev. 1998;56(11):317–33. https://doi.org/10.1111/j.1753-4887.1998.tb01670.x.
8. Bulduk EÖ, Ergene N, Baltacı AK, Gümüş H. Plasma antioxidant responses and oxidative stress following a 20 meter shuttle run test in female volleyball players. J Hum Sci. 2011;8(2):510–27.
9. Castillo Martínez M, Lozano-Casanova M, Sospedra I, Norte A, Gutiérrez-Hervás A, Martínez Sanz JM. Energy and macronutrients intake in indoor sport team athletes: systematic review. Nutrients. 2022;14(22):4755. https://doi.org/10.3390/nu14224755.
10. Chigachiaraguti M, Martínez-Galán B, Morhy Terrazas SI, Giolo F, Sambrano T, Cerizza G, Deminice R, Cristini E. Effect of creatine supplementation on muscle damage markers and physical performance in volleyball athletes. Cultura Ciencia y Deporte. 2020;16(15):377–385.
11. Clifford T, Howatson G, West D, Stevenson E. The potential benefits of red beetroot supplementation in health and disease. Nutrients. 2015;7(4):2801–22. https://doi.org/10.3390/nu7042801.
12. De Moraes AD, Andreato LV, Branco BH, da Silva EL, Gonçalves MA, Dos Santos RZ, Becker AM, da Silveira Cavalcante L, da Silva Casagrande F, Benetti M. Effects of N-acetylcysteine

supplementation on cellular damage and oxidative stress indicators in volleyball athletes. J Exerc Rehabil. 2018;14(5):802–9. https://doi.org/10.12965/jer.1836152.076.

13. Del Coso J, Pérez-López A, Abian-Vicen J, Salinero JJ, Lara B, Valadés D. Enhancing physical performance in male volleyball players with a caffeine-containing energy drink. Int J Sports Physiol Perform. 2014;9(6):1013–8. https://doi.org/10.1123/ijspp.2013-0448.
14. Díaz-Castro J, Guisado R, Kajarabille N, García C, Guisado IM, De Teresa C, Ochoa JJ. *Phlebodium decumanum* is a natural supplement that ameliorates the oxidative stress and inflammatory signalling induced by strenuous exercise in adult humans. Eur J Appl Physiol. 2012;112:3119–28. https://doi.org/10.1007/s00421-011-2295-3.
15. Dwi Nugroho MOHH, Sukarmin Y, Suhartini B. Fulfillment of nutrition intake of volleyball athletes to achieve achievement: a systematic review. Int J Multidiscip Res Anal. 2023;6:5. https://doi.org/10.47191/ijmra/v6-i5-56.
16. Eskici G, Gunay M, Baltaci AK, Mogulkoc R. The effect of different doses of zinc supplementation on serum element and lactate levels in elite volleyball athletes. J Appl Biomed. 2017;15(2):133–8. https://doi.org/10.1016/j.jab.2016.11.001.
17. Faiq DS, Essa SN, Muhialdeen SS. The effect of assisted training using supplementation (BCAA) in developing the special strength and accuracy of offensive skills in volleyball for youth. Egypt J Hosp Med. 2023;90(2):2398–403. https://doi.org/10.21608/ejhm.2023.286017.
18. Ferreira B, Neto A, Bergo Nader M, Ferraz Camargo, de Ornellas T, Passini Sodré Siviero IM, Padovani RM. Oxidative stress and muscle cell damage biomarkers monitoring in male volleyball athletes during a competitive season. Braz J Biomotricity. 2013;7:208–18.
19. Filip-Stachnik A, Kaszuba M, Dorozynski B, Komarek Z, Gawel D, Del Coso J, Klocek T, Spieszny M, Krzysztofik M. Acute effects of caffeinated chewing gum on volleyball performance in high-performance female players. J Hum Kinet. 2022;84(1):92–102. https://doi.org/10.2478/hukin-2022-0092.
20. García Verazaluce JJ, Vargas Corzo MDC, Aguilar Cordero MJ, Ocaña Peinado F, Sarmiento Ramírez Á, Guisado Barrilao R. Effect of phlebodium decumanum and coenzyme Q10 on sports performance in professional volleyball players. Nutr Hosp. 2015;31(1):401–14. https://doi.org/10.3305/nh.2015.31.1.8177.
21. Gerlinger-Romero F, Guimaraes-Ferreira L, Yonamine CY, Salgueiro RB, Nunes MT. Effects of beta-hydroxy-beta-methylbutyrate (HMB) on the expression of ubiquitin ligases, protein synthesis pathways and contractile function in extensor digitorum longus (EDL) of fed and fasting rats. J Physiol Sci. 2018;68(2):165–74. https://doi.org/10.1007/s12576-016-0520-x.
22. Gomez-Cabrera MC, Carretero A, Millan-Domingo F, Garcia-Dominguez E, Correas AG, Olaso-Gonzalez G, Viña J. Redox-related biomarkers in physical exercise. Redox Biol. 2021;42:101956. https://doi.org/10.1016/j.redox.2021.101956.
23. Hayat Z, Sharma S, Minhaj TM. Efficacy of caffeine on athletic performance: a systematic review and meta-analysis. Sci Sports. 2022;37(5–6):333–53. https://doi.org/10.1016/j.scispo.2021.07.011.
24. Heffernan SM, Horner K, De Vito G, Conway GE. The role of mineral and trace element supplementation in exercise and athletic performance: a systematic review. Nutrients. 2019;11(3):696. https://doi.org/10.3390/nu11030696.
25. Hemmatinafar M, Zaremoayedi L, Koushkie Jahromi M, Alvarez-Alvarado S, Wong A, Niknam A, Suzuki K, Imanian B, Bagheri R. Effect of beetroot juice supplementation on muscle soreness and performance recovery after exercise-induced muscle damage in female volleyball players. Nutrients. 2023;15(17):3763. https://doi.org/10.3390/nu15173763.
26. Institute of Medicine (US) Committee on Military Nutrition Research Caffeine for the sustainment of mental task performance: formulations for military operations. Washington (DC): National Academies Press (US). 2001.
27. Jakubowski JS, Nunes EA, Teixeira FJ, Vescio V, Morton RW, Banfield L, Phillips SM. Supplementation with the leucine metabolite β-hydroxy-β-methylbutyrate (HMB) does not improve resistance exercise-induced changes in body composition or strength in young subjects: a systematic review and meta-analysis. Nutrients. 2020;12(5):1523. https://doi.org/10.3390/nu12051523.
28. Jodra P, Lago-Rodríguez A, Sánchez-Oliver AJ, López-Samanes A, Pérez-López A, Veiga-Herreros P, San Juan AF, Domínguez R. Effects of caffeine supplementation on physical performance and mood dimensions in elite and trained-recreational athletes. J Int Soc Sports Nutr. 2020;17(1):2. https://doi.org/10.1186/s12970-019-0332-5.
29. Jones L, Bailey SJ, Rowland SN, Alsharif N, Shannon OM, Clifford T. The effect of nitrate-rich beetroot juice on markers of exercise-induced muscle damage: a systematic review and meta-analysis of human intervention trials. J Diet Suppl. 2022;19(6):749–71. https://doi.org/10.1080/19390211.2021.1939472.
30. Kaszuba M, Klocek O, Spieszny M, Filip-Stachnik A. The effect of caffeinated chewing gum on volleyball-specific skills and physical performance in volleyball players. Nutrients. 2023;15:91. https://doi.org/10.3390/nu15010091.
31. Kubota M, Hiruma E. Sasaki H. The Effects of creatine supplementation on jumping power and endurance of volleyball players. Adv Exerc Sports Physiol. 2003;9(3):91–6.
32. Lamontagne-Lacasse M, Nadon R, Goulet EDB. Effect of creatine supplementation on jumping performance in elite volleyball players. Int J Sports Physiol Perform. 2011;6(4):525–33.
33. Li N, Zhao G, Wu W, Zhang M, Liu W, Chen Q, Wang X. The efficacy and safety of vitamin c for iron supplementation in adult patients with iron deficiency anemia: a randomized clinical trial. JAMA Netw Open. 2020;3(11):e2023644. https://doi.org/10.1001/jamanetworkopen.2020.23644.
34. Lin YN, Tseng TT, Knuiman P, Chan WP, Wu SH, Tsai CL, Hsu CY. Protein supplementation increases adaptations to endurance training: a systematic review and meta-analysis. Clin Nutr. 2021;40(5):3123–32. https://doi.org/10.1016/j.clnu.2020.12.012.
35. Martín Martínez JP, Calleja González JM, Adsuar Sala JC, Gómez Pomares S, Carlos Vivas J, Pérez Gómez J. Short-term branched-chain amino acid supplementation does not enhance vertical jump in professional volleyball players. a double-blind, controlled, randomized study. Nutr Hosp. 2020;37:1007–11. https://doi.org/10.20960/nh.03032.
36. Martinović J, Dopsaj V, Kotur-Stevuljević J, Dopsaj M, Vujović A, Stefanović A, Nesić G. Proxidant* antioxidant balance in supplemented elite female volleyball athletes during a six week training period. J Sports Med Phys Fitness. 2011;51(1):145–52.
37. Martins NC, Dorneles GP, Blembeel AS, Marinho JP, Proença IC, da Cunha Goulart MJ, Moller GB, Marques EP, Pochmann D, Salvador M, Elsner V. Effects of grape juice consumption on oxidative stress and inflammation in male volleyball players: a randomized, double-blind, placebo-controlled clinical trial. Complement Ther Med. 2020;54:102570. https://doi.org/10.1016/j.ctim.2020.102570.
38. McClung JP. Iron, zinc, and physical performance. Biol Trace Elem Res. 2019;188:135–9. https://doi.org/10.1007/s12011-018-1479-7.
39. McGuinness LA, Higgins JPT. Risk-of-bias visualization (robvis): an R package and shiny web app for visualizing risk-of-bias assessments. Res Synth Methods. 2021;12:55–61. https://doi.org/10.1002/jrsm.1411.

40. Mielgo-Ayuso J, Zourdos MC, Calleja-González J, Urdampilleta A, Ostojic S. Iron supplementation prevents a decline in iron stores and enhances strength performance in elite female volleyball players during the competitive season. Appl Physiol Nutr Metab. 2015;40(6):615–22. https://doi.org/10.1139/apnm-2014-0500.
41. Nemati J, Hemmatinafar M, Niknam A, Nikahd M, Zeighami N, Imanian B, Safari K, Jahaniboushehri N, Suzuki K. Effects of different doses of caffeine supplementation on collegiate male volleyball players' specific performance and skills: a randomized, double-blind, placebo-controlled, crossover study. Nutrients. 2023;15(18):4049. https://doi.org/10.3390/nu15184049.
42. Nyberg M, Christensen PM, Blackwell JR, Hostrup M, Jones AM, Bangsbo J. Nitrate-rich beetroot juice ingestion reduces skeletal muscle O_2 uptake and blood flow during exercise in sedentary men. J Physiol. 2021;599(23):5203–14. https://doi.org/10.1113/JP281995.
43. Osuka Y, Kojima N, Wakaba K, Miyauchi D, Tanaka K, Kim H. Effects of resistance training and/or beta-hydroxy-beta-methylbutyrate supplementation on muscle mass, muscle strength and physical performance in older women with reduced muscle mass: protocol for a randomised, double-blind, placebo-controlled trial. BMJ Open. 2019;9(2):e025723. https://doi.org/10.1136/bmjopen-2018-025723.
44. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. https://doi.org/10.1136/bmj.n71.
45. Perez-Lopez A, Salinero JJ, Abian-Vicen J, Valades D, Lara B, Hernandez C, Areces F, Gonzalez C, Del Coso J. Caffeinated energy drinks improve volleyball performance in elite female players. Med Sci Sports Exerc. 2015;47(4):850–6. https://doi.org/10.1249/MSS.0000000000000455.
46. Pfeifer DR, Arvin KM, Herschberger CN, Haynes NJ, Renfrow MS. A low dose caffeine and carbohydrate supplement does not improve athletic performance during volleyball competition. Int J Exerc Sci. 2017;10(3):340.
47. Plotkin DL, Delcastillo K, Van Every DW, Tipton KD, Aragon AA, Schoenfeld BJ. Isolated leucine and branched-chain amino acid supplementation for enhancing muscular strength and hypertrophy: a narrative review. Int J Sport Nutr Exerc Metab. 2021;31(3):292–301. https://doi.org/10.1123/IJSNEM.2020-0356.
48. Portal S, Zadik Z, Rabinowitz J, Pilz-Burstein R, Adler-Portal D, Meckel Y, Cooper DM, Eliakim A, Nemet D. The effect of HMB supplementation on body composition, fitness, hormonal and inflammatory mediators in elite adolescent volleyball players: a prospective randomized, double-blind, placebo-controlled study. Eur J Appl Physiol. 2011;111:2261–9. https://doi.org/10.1007/s00421-011-1855-x.
49. Rebelo A, Pereira JR, Cunha P, Coelho-e-Silva MJ, Valente-dos-Santos J. Training stress, neuromuscular fatigue and well-being in volleyball: a systematic review. BMC Sports Sci Med Rehabil. 2024;16(1):17. https://doi.org/10.1186/s13102-024-00807-7.
50. Sarkhosh-Khorasani S, Sangsefidi ZS, Hosseinzadeh M. The effect of grape products containing polyphenols on oxidative stress: a systematic review and meta-analysis of randomized clinical trials. Nutr J. 2021;20:25. https://doi.org/10.1186/s12937-021-00686-5.
51. Setaro L, Santos-Silva PR, Nakano EY, Sales CH, Nunes N, Greve JM, Colli C. Magnesium status and the physical performance of volleyball players: effects of magnesium supplementation. J Sports Sci. 2014;32(5):438–45. https://doi.org/10.1080/02640414.2013.828847.
52. Siquier-Coll J, Delgado-García G, Soto-Méndez F, Liñán-González A, García R, González-Fernández FT. The effect of caffeine supplementation on female volleyball players' performance and wellness during a regular training week. Nutrients. 2023;16(1):29. https://doi.org/10.3390/nu16010029.
53. Souglis A, Bogdanis GC, Giannopoulou I, Papadopoulos CH, Apostolidis N. Comparison of inflammatory responses and muscle damage indices following a soccer, basketball, volleyball and handball game at an elite competitive level. Res Sports Med. 2015;23(1):59–72. https://doi.org/10.1080/15438627.2014.975814.
54. Stares A, Bains M. The Additive effects of creatine supplementation and exercise training in an aging population: a systematic review of randomized controlled trials. J Geriatr Phys Ther. 2020;43(2):99–112. https://doi.org/10.1519/JPT.0000000000000222.
55. Stein JA, Ramirez M, Heinrich KM. Acute caffeine supplementation does not improve performance in trained CrossFit® athletes. Sports. 2020;8(4):54. https://doi.org/10.3390/sports8040054.
56. Sterne JA, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, Cates CJ, Cheng HY, Corbett MS, Eldridge SM, Emberson JR. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ. 2019. https://doi.org/10.1136/bmj.l4898.
57. Taghizadeh M, Malekian E, Memarzadeh MR, Mohammadi AA, Asemi Z. Grape seed extract supplementation and the effects on the biomarkers of oxidative stress and metabolic profiles in female volleyball players: a randomized, double-blind, placebo-controlled clinical trial. Iran Red Crescent Med J. 2016;18(9):e31314. https://doi.org/10.5812/ircmj.31314.
58. Teixeira FJ, Matias CN, Monteiro CP, Valamatos MJ, Reis JF, Batista A, Oliveira AC, Alves F, Sardinha LB, Phillips SM. No effect of HMB or α-HICA supplementation on training-induced changes in body composition. Eur J Sport Sci. 2019;19(6):802–10. https://doi.org/10.1080/17461391.2018.1552723.
59. Volpe SL. Magnesium and the athlete. Curr Sports Med Rep. 2015;14(4):279–83. https://doi.org/10.1249/JSR.0000000000000178.
60. Wickham KA, Spriet LL. Administration of caffeine in alternate forms. Sports Med. 2018;48:79–91. https://doi.org/10.1007/s40279-017-0848-2.
61. Zare R, Kimble R, Ali Redha A, Cerullo G, Clifford T. How can chokeberry (aronia) (poly)phenol-rich supplementation help athletes? a systematic review of human clinical trials. Food Funct. 2023;14(12):5478–91. https://doi.org/10.1039/d3fo00336a.
62. Zbinden-Foncea H, Rada I, Gomez J, Kokaly M, Stellingwerff T, Deldicque L, Peñailillo L. Effects of caffeine on countermovement-jump performance variables in elite male volleyball players. Int J Sports Physiol Perform. 2018;13(2):145–50. https://doi.org/10.1123/ijspp.2016-0705.