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Advantages of different dietary supplements for elite combat sports athletes: a systematic review and Bayesian network meta-analysis

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With an increasing number of studies delving into the impact of dietary supplements on combat sports performance, researchers are actively seeking a more efficient dietary supplement for use in these sports. Nonetheless, controversies persist. Hence, we undertook a systematic review and Bayesian network meta-analysis to discern the most effective dietary supplements in combat sports by synthesizing the available evidence. We conducted a comprehensive search across PubMed, Web of Science, Cochrane, Embase, and SPORTDiscus, covering the period from their establishment to November 2, 2023. Our aim was to identify randomized controlled trials that evaluated the benefits of various dietary supplements for elite combat sports athletes. The risk of bias in these trials was assessed using the revised Cochrane Risk of Bias Tool for Randomized Trials. Subsequently, we employed Bayesian network meta-analysis through R software and Stata 15.0. During the analysis, we performed subgroup analysis based on the type of combat, distinguishing between striking and grappling disciplines. The analysis is based on 67 randomized controlled trials that meet all the inclusion criteria, involving 1026 elite combat sports athletes randomly assigned to 26 different dietary supplements or placebos. Results from the 50 trials included in the network meta-analysis indicate that compared to a placebo, sodium bicarbonate combined with caffeine (SMD: 2.3, 95% CrI: 1.5, 3.2), caffeine (SMD: 0.72, 95% CrI: 0.53, 0.93), beta-alanine (SMD: 0.58, 95% CrI: 0.079, 1.1), and sodium bicarbonate (SMD: 0.54, 95% CrI: 0.30, 0.81) was associated with a statistically significant increase in blood lactate concentrations. Compared to placebo, caffeine (SMD: 0.27, 95% CrI: 0.12, 0.41) was associated with a statistically significant increase in the final heart rate. Compared to placebo, creatine combined with sodium bicarbonate (SMD: 2.2, 95% CrI: 1.5, 3.1), creatine (SMD: 1.0, 95% CrI: 0.38, 1.6), and sodium bicarbonate (SMD: 0.42, 95% CrI: 0.18, 0.66) was associated with a statistically significant increase in mean power. Compared to placebo, creatine combined with sodium bicarbonate (SMD: 1.6, 95% CrI: 0.85, 2.3), creatine (SMD: 1.1, 95% CrI: 0.45, 1.7), and sodium bicarbonate (SMD: 0.35, 95% CrI: 0.11, 0.57) was associated with a statistically significant increase in peak power. Compared to placebo, caffeine (SMD: 1.4, 95% CrI: 0.19, 2.7) was associated with a statistically significant increase in the number of kicks. Compared to placebo, caffeine (SMD: 0.35, 95% CrI: 0.081, 0.61) was associated with a statistically significant increase in the number of throws. This study suggests that a range of dietary supplements, including caffeine, sodium bicarbonate, sodium bicarbonate combined with caffeine, creatine, creatine combined with sodium bicarbonate, and beta-alanine can improve the athletic performance of elite combat sports athletes.

Keywords Combat sports, Elite athletes, Ergogenic aids, Supplementation, Performance

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Combat sports encompass competitive contact activities that involve various striking, grappling, and surrendering techniques. While these sports vary significantly in rules, traditions, and techniques, they all share the common element of physical confrontation between participants, with the winner determined by specific criteria as per the sport's rules. Notably, combat sports, including boxing and mixed martial arts, boast millions of enthusiasts[1,2]. It's noteworthy that over 25% of Summer Olympic medals are dedicated to combat sports[3]. Based on the rules and characteristics, combat sports can be categorized into grappling (involving gripping, throwing, ground combat, choking, and joint locking), striking (emphasizing techniques like punching and kicking), and mixed martial arts combining grappling and striking[4]. Physically demanding, these sports require participants to develop specific physical and physiological attributes tailored to each event. Sports involving punching and kicking demand greater explosiveness and strength, requiring explosive movements of the upper and lower extremities[5]. Conversely, grappling actions place a higher emphasis on isometric and concentric muscle strength[6,7]. Moreover, the specific limb development in combat sports varies due to their distinct movements. For instance, boxing and judo heavily rely on upper limbs, taekwondo focuses on lower limbs, and karate utilizes both upper and lower limbs[5,8–11]. Generally, combat sports are characterized by intermittent strenuous activities, featuring patterns of effort and the "exercise-relative recovery" sequence[12]. Intermittent high-intensity work, marked by short but intense bursts of force and strength movements, is a hallmark of combat sports[7]. This demands effective participation in anaerobic metabolism[7], involving the generation of energy through intramuscular adenosine triphosphate (ATP) and creatine phosphate, and/or anaerobic glycolysis during short periods of exercise[4]. This is evident in elevated blood lactate levels post-fight[4]. However, combat sports not only entail high-intensity intermittent exercise but also the repetitive execution of interspersed low-intensity movements[13–16]. The energy demand of these exercises underscores the significant involvement of aerobic metabolism[13,16,17].

Elite combat athletes require peak physical performance and swift recovery to excel in demanding and dynamic disciplines. Achieving and maintaining optimal nutritional status is a crucial component of combat training regimens. Among these, dietary supplements play a pivotal role in addressing the unique nutritional needs of combat athletes[18,19]. Dietary supplements are defined as "foods, food ingredients, nutrients, or non-food compounds ingested with intent, in addition to habitual diets, to achieve specific health and/or performance benefits"[20]. The consensus of the International Olympic Committee (IOC) acknowledges that dietary supplements serve multiple purposes, such as enhancing athletic or cognitive performance, expediting recovery from strenuous physical activity, or preventing nutritional deficiencies[21]. The evidence supporting the benefits of dietary supplements is of particular interest to teams collaborating with elite combat athletes, including nutritionists, doctors, and sports scientists. Successfully implementing nutritional interventions involves understanding the potency of dietary supplements and how to use them based on individual goals and requirements. While dietary supplements can be beneficial, it's essential to recognize that they may not be without risks, such as the presence of prohibited substances[18]. In combat sports, dietary supplements frequently form part of a nutritional strategy aimed at bolstering athletes' performance and recovery[22]. Recent years have witnessed evidence regarding the impact of dietary supplements on athletic performance in combat athletes[1,8,23–29]. However, existing studies have predominantly used classical pairwise meta-analyses, which are not the most effective statistical approach for systematically comparing the benefits of different ergogenic dietary supplements in combat sports[1,8,23–29]. Compared with classical meta-analysis, network meta-analysis allows us to compare and rank the effects of multiple interventions on outcome variables simultaneously[30].

As more and more studies explore the effects of dietary supplements on combat sports performance, researchers are trying to find a more effective dietary supplement in combat sports. However, there is still controversy so far. Therefore, we conducted this systematic review and Bayesian network meta-analysis to provide a comprehensive overview of the advantages offered by different dietary supplements tailored to elite combat sports athletes. By synthesizing the available evidence, we sought to identify the most effective dietary supplements that help improve performance, injury prevention and overall health in this elite group. This paper provides advice on dietary supplement selection for future elite athletes in terms of training and unique nutritional needs.

Materials and methods

Study registration

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Network Meta-Analyses (PRISMA-NMA)[31] recommendations and was prospectively registered with the PROSPERO (ID: CRD42023482919).

Eligibility criteria

Inclusion criteria

P(Population): The population in our systematic review consists of adult well-trained elite combat athletes who were categorized as tier 3, 4, or 5 under a recently developed framework for athletes[32], including judo, wrestling, jiu-jitsu, taekwondo, boxing, karate, mixed martial arts, sanda, fencing, kendo.

I(Intervention): The intervention group in this systematic review utilized various dietary supplements within reasonable limits, excluding any stimulant substances specified by the World Anti-Doping Agency. The usage of these supplements is not limited to single use.

C(Comparison): The controls for our systematic review were those who received placebo or a blank control group that did not receive any supplements.

O(Outcome): The primary outcome measures of our systematic review included rating of perceived exertion, final heart rate, blood lactate concentration, peak power, mean power, special judo fitness test-number of throws, special judo fitness test index, taekwondo kick test-number of kicks, simulated competition-number of attacks, and grip strength. Secondary outcome measures included biochemical parameters and side effects.

S(Study design): (1) This systematic review included randomized controlled trials or randomized controlled crossover designs to assess the beneficial effects of treatment; (2) English language-only articles.

Exclusion criteria
P (Population): We need to exclude underage and non-elite combat athletes from our study.

I(Intervention): It is necessary to exclude the use of substances prohibited by the World Anti-Doping Agency (WADA) in our study.

C(Comparison): none.

O(Outcome): none.

S(Study design): (1) Conference abstracts published without peer review; (2) Repeatedly published studies in the same experiment; (3) Non-English articles; (4) Review papers.

Data sources and search strategy
We conducted a systematic search in PubMed, Web of Science, Cochrane, Embase, and SPORTDiscus from inception to November 2, 2023. The searches were performed using subject headings (MeSH) and free terms, and there were no restrictions on region or year of publication. The detailed search strategy is illustrated in Table S1.

Study selection & data extraction
We imported the collected literature into Endnote 21.0 and meticulously reviewed the titles and abstracts to initially filter the original studies aligning with our systematic review. Subsequently, we obtained the full text of those studies. Following this, we conducted a thorough reevaluation of the full text to identify the original studies that ultimately met the criteria for our systematic review. Prior to data extraction, we devised a standardized form encompassing key information, including title, primary author, publication year, study design, DOI/PMID, author's country, combat type, intervention type, intervention details, number of cases, total participants, gender, age, height, weight, body fat percentage, BMI, years of combat/level, treatment duration, and outcome indicators. The screening of literature and data extraction were independently carried out by two researchers (HL, XZ). Upon completion, a cross-check was performed, and in case of any discrepancies, a third researcher (CX) was consulted to assist in resolving disputes.

Risk of bias in studies
The quality evaluation was conducted by two researchers (HL, XZ) using the RCT bias risk assessment tool of the Cochrane Collaborative Network for bias risk assessment. This evaluation tool[33] included the following 7 items: The method of generating random sequences, allocation concealment, blinding of subjects and intervention providers, blinding of outcome evaluators, incomplete outcome data, selective outcome reporting, and other sources of bias, with each item evaluated as low bias, high bias, or unclear.

Synthesis methods
We utilized network graphs to visually represent the geometric arrangement of diverse intervention methods, effectively displaying the quantity of studies and participants for each comparison. This approach facilitated a comprehensive overview of the evidence base. By conducting direct comparative trials, the network formed by linking treatments can be illustrated as a graph, with nodes representing different supplements. The connection lines between nodes corresponded to direct head-to-head comparisons between the interventions. The size of the nodes was in accordance with the number of participants in each type of supplement and the thickness of the connection proportional to the number of studies accumulated in trials directly comparing the two interventions. Graphical network diagrams were created using Stata 15.0 (Stata Corporation, College Station, TX).

The method of Markov Chain Monte Carlo (MCMC) was utilized for modeling, with 4 Markov chains running simultaneously. The annealing times were established at 20,000, and modeling was concluded after 50,000 simulated iterations. Network meta-analysis employed a Bayesian random effects model to compare the effects of interventions, for the purpose of evaluating the effectiveness of various intervention methods. To evaluate the statistical significance of the intervention effect, a significance threshold of $p < 0.05$ was established. Additionally, 95% credible intervals (CrIs) were employed to gain further insights into statistical significance. A result is regarded as statistically significant ($p < 0.05$) if the 95% CrI does not encompass zero. In contrast, if the 95% CrI does include zero, the result is deemed not statistically significant ($p > 0.05$). The I^2 statistic was utilized to assess the level of heterogeneity among the various studies. The I^2 values indicative of low, medium, and high levels of heterogeneity are 25%, 50%, and 75%, respectively[34]. The initial analysis entailed assessing the consistency between direct evidence and indirect evidence. We compared the outcomes of the consistency model (assuming direct and indirect evidence are consistent) with the inconsistency model (allowing for potential differences) to evaluate the overall consistency hypothesis. The local inconsistency hypothesis was examined using the node splitting method, which separates each compared direct and indirect evidence to evaluate their consistency. If the consistency hypothesis is upheld, we will proceed to use the consistency model for further analysis. Additionally, each intervention measure underwent ranking based on the surface under the cumulative ranking (SUCRA), and a league table was generated to compare the variations in effects among different intervention measures[35]. Throughout the analysis process, subgroup analysis was performed based on the type of combat (striking and grappling). A funnel plot was utilized to visually illustrate the publication bias among the studies. In case of multi-arms study with variation in dose or time-point, the results from the different groups/conditions were aggregated. Our research analysis was conducted in R 4.3.2 (R development Core Team, Vienna, http://www.R-project.org), and the analysis script can be found in Supplementary Material 1.

Results

Study selection

Figure 1 illustrates the number of publications considered and excluded at each phase of the literature search. The initial search yielded 20,731 records, with 12,551 duplicates (from various databases) being eliminated. Following the review of titles and abstracts, 133 full-text articles were retrieved for eligibility assessment. After a thorough examination of each document, 66 studies were excluded for various reasons: 20 studies lacked useful data (no available outcome measures), 19 studies did not meet our inclusion criteria (non-randomized controlled trials), 10 studies involved non-elite athlete participants, and 11 studies included underage participants. Additionally, 4 studies were non-English papers, and 2 studies were conference abstracts (Supplementary Material 2). As a result, a total of 67 published papers ultimately satisfied the inclusion criteria. Among them, 50[36–85]. papers were included in the quantitative network meta-analysis. Additionally, 17 papers[86–102] were included in the qualitative systematic review.

Study characteristics

The characteristics of the included studies are shown in Table 1. A total of 1026 elite combat athletes were recruited in the 67 studies reviewed. A total of 508 elite athletes were recruited from grappling events, of whom 287 were from judo[37,38,40,41,43,44,47,53,56–58,62,64,65,67,68,72–74,78–81,85], 113 from jiu-jitsu[39,41,48,52,56,60,69,71], 83 from wrestling[36,51,61,66] and 25 from jujitsu and wrestling without a clear sample of combat types[83,84]. A total of 445 elite athletes were recruited in the striking event, of whom 257 were from taekwondo[42,45,46,49,50,54,55,59,65,75–77,82], 70 from boxing[86,94–96,98], 26 from karate[89,97], 36 from kendo[86,93], 36 from fencing[88,101,102] and 20 from sanda[92]. Additionally, there were 57 athletes of mixed martial arts[90,91,99] and 16 combat athletes[100] without a clear description of the type of combat.

From the gender distribution of the sample, more male athletes participated. Forty studies recruited male athletes (598 athletes), two studies[37,68] recruited female athletes (16 athletes), 12 studies combined male and female athletes (136 male and 99 female athletes), and 14 studies did not specify the sample gender (177 athletes).

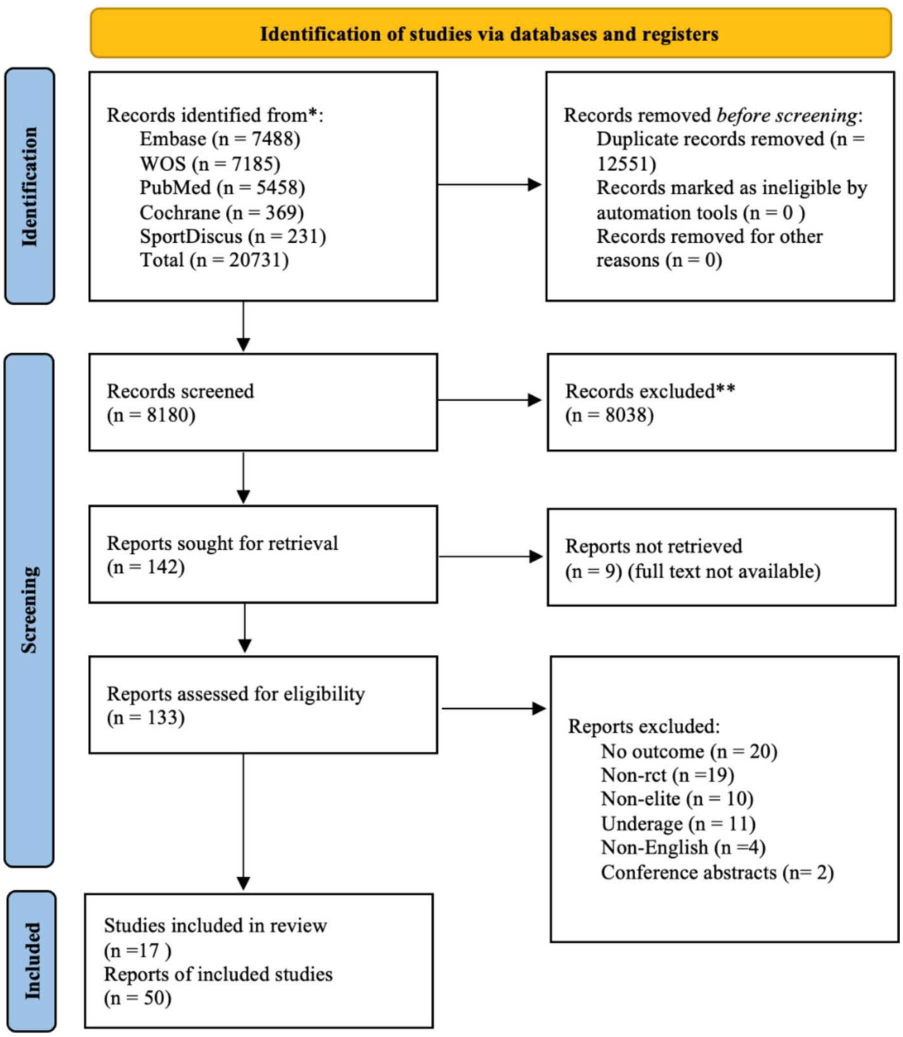

Fig. 1. Flowchart of screening process.

No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
1	H. U. Yavuz	2014	Cross-over design	North Cyprus	Wrestling	1.ARG 2.PLA	Not mentioned	9	All-male	24.7(SD:3.8)	174.2(SD:5.2)(cm)	80.4(SD:4.1)	None
2	H. Wei	2010	RCT	Taiwan	Judo	1.HMB 2.CG	1.HMB: 4 2.CG: 4	8	All-female	HMB:21.1(SE:0.6) CG:21.8 (SE:1.1)	HMB:1.6(SE:0.02)(m) CG:1.57 (SE:0.03)(m)	HMB:57.28(SE:2.43) CG:58.00(SE:2.53)	BMI: HMB:20.23(SE:2.08) CG:21.78(SE:1.67)
3	J. C. B. Viana	2021	Cross-over design	Brazil	Judo	1.CM 2.PLA	Not mentioned	10	All-male	19.4(SD:1.8)	None	78.7(SD:10.5)	None
4	M. V. A. Verli	2021	RCT	Brazil	Jiu-Jitsu	1. CHO(1):supplementation immediately before a fight 2. CHO(2):supplementation 30 min before a fight 3.CG	1.CHO:4 2.CHO:4 3.CG:4	12	Not mentioned	CHO(1): 36.75 (SD: 4.50) CHO(2): 31.75 (SD: 6.18) CG: 25.75 (SD: 8.34)	CHO(1): 1.77 (SD: 0.06)(m) CHO(2): 1.75 (SD: 0.11)(m) CG: 1.78 (SD: 0.02)(m)	CHO(1): 84.35 (SD: 15.58) CHO(2): 82.27 (SD: 0.07) CG: 82.92 (SD: 16.29)	BMI: CHO(1): 26.98 (SD: 5.47) CHO(2): 26.71 (SD: 3.09) CG: 26.01(SD: 4.94)
5	P. H. Tsai	2009	RCT	Taiwan	Judo	1.ARG 2.PLA	Not mentioned	12	All-male	20.25(SE:0.25)	175.33(SE:1.32)(cm)	75.75(SE:2.89)	BMI 24.58(SE:0.72)
6	G. Tobias	2013	Cross-over design	Brazil	Judo Jiu-jitsu	1.BA_PLA 2.SB_PLA 3.BA_SB 4.PLA_PLA	1.BA_PLA:10 2.SB_PLA:9 3.BA_SB:9 4.PLA_PLA:9	37	All-male	BA_PLA:26(SD:4) SB_PLA:23(SD:4) BA_SB:26(SD:5) PLA_PLA:26(SD:5)	None	BA_PLA: 79.9 (SD:8.0) SB_PLA:81.2(SD:11.6) BA_SB:77.1(SD:9.0) PLA_PLA:78.0(SD:9.1)	None
7	F. Sun	2022	Cross-over design	Hong Kong	Taekwondo	1.CAF 2.PLA	Not mentioned	10	Males: 6 Females: 4	Male: 27 (SD:2) Female: 25 (SD:3)	Male: 174 (SD:7)(cm) Female: 162 (SD:6) (cm)	Male: 71 (SD:11) Female: 58 (SD:1)	None
8	S. Sterkowicz	2012	RCT	Poland	Judo	1.CRM 2.PLA	1.CRM:5 2.PLA:5	10	All-male	21.2(SD:3.3)	1.75(SD:0.06)(m)		BMI: All: 24.59(SD:3.41) CRM: 26.92(SD:3.41) PLA: 22.27(SD:0.97)
9	M. Souissi	2014	RCT	Tunisia	Judo	1.CAF 2.PLA	Not mentioned	10	Not mentioned	21.08(SD:1.16)	1.76(SD:6.57)(m)	83.75(SD:20.2)	None
10	J. C. Siegler	2010	RCT	United Kingdom	Boxing	1.SB 2.PLA	Not mentioned	10	Not mentioned	22(SD:3)	177.8(SD:8.1)(cm)	73.1(SD:10.0)	None
11	K. Shimizu	2015	RCT	Japan	Kendo	1.CoQ10 2.PLA	1.CoQ10:9 2.PLA:9	18	All-male	CoQ10: 20.4(SE: 1.0) PLA: 19.7(SE:0.9)	CoQ10: 171.9(SE: 5.9) (cm) PLA: 172.9(SE:5.0) (cm)	CoQ10: 72.3(SE: 7.8) PLA: 72.3(SE:7.9)	BMI (kg·m – 2): CoQ10: 24.4(SE: 1.3) PLA: 24.1(SE:1.6) Body fat(%): CoQ10: 14.8(SE: 2.3) PLA: 14.7(SE:1.8)

Continued

No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
12	A. Sarshin	2021	RCT	Iran	Taekwondo	1.CR_SB 2.CR 3.SB 4.PLA 5.CG	1.CR_SB:8 2.CR:8 3.SB:8 4.PLA:8 5.CG:8	40	All-male	CR_SB: 22.9(SD:1.8) CR: 21.4(SD:1.1) SB: 23.1(SD:2.4) PLA: 22.6(SD:1.7) CG: 22.4(SD:1.7)	CR_SB: 182.5(SD:10.5)(cm) CR: 181.3(SD:5.1)(cm) SB: 179.3(SD:6.5)(cm) PLA: 180.1(SD:8.4)(cm) CG: 179.8(SD:6.3)(cm)	CR_SB: 73.6 (SD:8.5) CR: 72.0(SD:11.0) SB: 71.5(SD:10.9) PLA: 72.2(SD:7.2) CG: 74.6(SD:6.4)	None
13	V. G. F. Santos	2014	Cross-over design	Brazil	Taekwondo	1.CAF 2.PLA	Not mentioned	10	All-male	24.9(SD:7.3)	1.75(SD:0.06)(m)	77.2(SD:12.3)	None
14	M. Saldanha da Silva Athayde	2019	Cross-over design	Brazil	Judo	1.CAF 2.PLA	Not mentioned	12	All-male	23.1(SD:4.2)	172.7(SD:5.4)(cm)	75.7(SD:15.1)	Body fat (%): 13.35(SD:6.2)
15	G. Rowlatt	2017	RCT	United Kingdom	Fencing	1.CHO(maltodextrin solution) 2.PLA	Not mentioned	9	Males: 7 Females: 2	31.2(SD:14.3)	178(SD:8)(cm)	81.4(SD:16.5)	None
16	S. Rezaei	2019	Cross-over design	Iran	Karate	1.CAF 2.SB 3.CAF_SB 4.PLA 5.CG	Not mentioned	8	Not mentioned	20.5(SD:2.4)	1.78(SD:0.06 m)	67.8(SD:7.7)	Body fat(%): 10(SD:3)
17	L. Ragone	2020	Cross-over design	Brazil	Jiu-Jitsu	1.SB:0.3 g/kg of body weight 2.PLA	Not mentioned	10	All-male	22.2(SD: 3.9)	174(SD: 0.07)(cm)	74.5(SD: 8.9)	None
18	K. Przewłócka	2023(a)	RCT	Poland	Mixed martial arts	1.VITD_PB 2.PLA: VITD	1.VITD_PB:11 2.PLA(VITD):12	23	All-male	VITD_PB: 24.7 (SD:6.5) PLA: 26.2 (SD:4.0)	VITD_PB: 182.2 (SD:9.3)(cm) PLA: 179.3 (SD:7.7)(cm)	VITD_PB: 81.1 (SD:12.0) PLA: 80.2 (SD:9.8)	None
19	K. Przewłócka	2023(b)	RCT	Poland	Mixed martial arts	1.VITD_PB 2.PLA: VITD	1.VITD_PB:11 2.PLA(VITD):12	23	All-male	VITD_PB: 24.7 (SD:6.5) PLA: 26.2 (SD:4.0)	VITD_PB: 182.2 (SD:9.3)(cm) PLA: 179.3 (SD:7.7)(cm)	VITD_PB: 81.1 (SD:12.0) PLA: 80.2 (SD:9.8)	None
20	I. Ouergui	2022	Cross-over design	Tunisia	Taekwondo	1.CAF 2.PLA	Not mentioned	20	Males: 10 Females: 10	17.5(SD:0.7)	168(SD:9)(cm)	59.2(SD:10.0)	None

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No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
21	I. Ouergui	2023	Cross-over design	Tunisia	Taekwondo	1.CAF (3 mg/kg of body mass) 2.PLA 3.CG	Not mentioned	52	Males: 26 Females: 26	Elite male: 18.2 (SD:0.8) Elite female: 17.7(SD:0.6) Sub-elite male: 17.7(SD:0.8) Sub-elite female:17.3 (SD:0.5)	Elite male: 182 (SD:7) (cm) Elite female: 167 (SD:10)(cm) Sub-elite male: 171(SD:9)(cm) Sub-elite female: 164 (SD:7)(cm)	Elite male: 61(SD:9) Elite female: 50 (SD:5) Sub-elite male: 61 (SD:11) Sub-elite female: 55(SD:8)	None
22	S. Oliynyk	2010	RCT	Kingdom of Saudi Arabia	Wrestling	1.ANT 2.PLA	1.ANT:10 2.PLA:6	16	All-male	ANT: 19.40 (SD:0.8433) PLA: 18.67 (SD:0.8165)	ANT: 173.1 (SD:6.574) (cm) PLA: 176.2 (SD:9.579) (cm)	ANT: 72.10 (SD:8.543) PLA: 75.50 (SD:11.67)	BMI: ANT: 24.00 (SD:1.76) PLA: 24.33 (SD:1.86)
23	M. Merino-Fernández	2022	Cross-over design	Spain	Jiu-Jitsu	1.CAF(3 mg/kg body mass) 2.PLA	Not mentioned	22	Males: 11 Females: 11	22(SD: 4)	1.70(0.9)(m)	66.6(SD: 10.8)	None
24	R. Lopez-Grueso	2014	RCT	Spain	Judo	1.BA 2.PLA	1.BA:2 2.PLA:3	5	Males: 2 Females: 3	BA: 23.5 (SD:0.7) PLA: 25.0 (SD:1.0)	BA: 1.60 (SD:0.04)(m) PLA: 1.70 (SD:0.04) (m)	BA: 61.4 (SD:1.4) PLA: 66.3 (SD:9.9)	None
25	J. P. Lopes-Silva	2015	Cross-over design	Brazil	Taekwondo	1.CAF (5 mg/kg) 2.PLA	None	10	All-male	21(SD:4)	1.80(SD:0.08)(m)	71.0 (SD:12.9)	None
26	J. P. Lopes-Silva	2018	Cross-over design	Brazil	Taekwondo	1.SB 2.PLA	None	9	All-male	19.4(SD:2.2)	179.3(SD:3.5)(cm)	70.4(SD:8.9)	None
27	J. P. Lopes-Silva	2022	Cross-over design	Brazil	Judo Jiu-jitsu	1.CAF (5 mg/kg) 2.PLA	judo: $n=2$ jiu-jitsu: $n=8$	10	Not mentioned	25.2(SD:5.3)	170(SD:0.1)(cm)	72.8(SD:9.8)	Body fat (%): 14.4(SD:4.9)
28	J. P. Lopes-Silva	2014	Cross-over design	Brazil	Judo	1.CAF 2.PLA 3.CG	None	6	All-male	25.3(SD:5.7)	167.0(SD:3.6 cm)(cm)	71.1(SD:13.5)	Body fat (%): 13.2(SD:11.2)
29	T. H. Liu	2009	Cross-over design	Taiwan	Judo	1.ARG 2.PLA	None	10	All-male	20.2(SE:0.6)	1.72(SE:0.02)(m)	ARG:73.3(SE:2.1) PLA:73.6(SE:2.0)	None
30	M. Koohkan	2023	RCT	Iran	Sanda	1.VITC_VITE 2.PLA	1.VITC_VITE:10 2.PLA:10	20	All-male	VITC_VITE: 22.3 (SD: 0.95) PLA: 21.8 (SD: 1.32)	VITC_VITE: 174.2 (SD: 1.87) (cm) PLA: 174.8 (SD: 1.03) (cm)	VITC_VITE: 71.1 (SD: 1.85) PLA: 72 (SD: 1.15)	BMI: VITC_VITE: 23.44 (SD: 0.74) PLA: 23.56 (SD: 0.43)

Continued

No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
31	M. Kon	2008	RCT	Japan	Kendo	1.CoQ10 2.PLA	1.CoQ10:10 2.PLA:8	18	All-male	CoQ10: 20.5 (SD: 1) PLA: 19.6 (SD: 1)	CoQ10: 171.3 (SD: 5.8) (cm) PLA: 172.7 (SD: 5.8) (cm)	CoQ10: 71.3 (SD: 8) PLA: 71.9 (SD: 8.3)	Body fat(%): CoQ10: 14.5 (SD: 2.4) PLA: 14.5 (SD: 1.9)
32	K. J. Kim	2018	RCT	Republic of Korea	Boxing	1.BA 2.PLA	1.BA:9 2.PLA:10	19	All-male	BA: 23 (SD: 1.82) PLA: 22.2 (SD: 2.21)	BA: 180.41 (SD: 7.42) (cm) PLA:178.59 (SD: 6.33) (cm)	BA: 77.25 (SD: 20.64) PLA: 75.31 (SD: 19.21)	Body fat (%): BA: 12.30 (SD: 7.89) PLA: 13.87 (SD: 6.44) BMI: BA: 23.60 (SD: 5.51) PLA: 24.03 (SD: 4.49)
33	S. Khosravi	2021	Cross-over design	Iran	Taekwondo	1.BRT(12.8 mmol NO3−) 2.PLA	1.BRT:6 2.PLA:6	12	All-male	19.2(SD:1.6)	181.5(SD:9.2)(cm)	66.4(SD:9.2)	BMI: 20.1(SD:2.1)
34	P. Jodra	2020	Cross-over design	Spain	Boxing	1. CAF (6 mg/kg) 2.PLA	1.CAF:4 2.PLA:4	18	All-male	Elite Athlete: 22 (SD: 1.8)	Elite Athlete: 1.69 (SD: 0.09) (m)	Elite athletes: 65.6 (SD: 10.8)	BMI: Elite Athletes: 22.7 (SD: 1.3)
35	F. Javier Diaz-Lara	2016	RCT	Spain	Jiu-Jitsu	1.CAF 2.PLA	None	14	Not mentioned	29.2(SD: 3.3)	173.8(SD: 6.2)(cm)	71.3(SD: 9.1)	Body fat(%): 8.5(SD: 1.5)
36	T. R. Jang	2011	Cross-over design	Taiwan	Wrestling	1.BCAA_CHO_ARG(1 g/kg glucose + 0.1 g/kg Arg + 0.1 g/kg BCAA) 2.CHO(1.2 g/kg glucose) 3.PLA	None	9	All-male	19.2(SEM:0.4)	1.69(SEM:0.02)(m)	72.18(SEM:2.71)	Body fat(%): 15.5(SEM:1.6%)
37	M. Halz	2022	RCT	Poland	Judo	1.BA 2.PLA	1.BA:8 2.PLA:8	16	Not mentioned	BA: 20.7 (SD: 3.2) PLA: 22.1 (SD: 2.8)	BA: 177.2 (SD: 2.6) (cm) PLA: 178.3 (SD: 4.9) (cm)	BA: 81.5 (SD: 3.9) PLA: 78.4 (SD: 5.1)	Body fat(%): BA: 10.9 (SD: 2.6) PLA: 9.8 (SD: 3.2)
38	L. A. Gough	2019	RCT	United Kingdom	Boxing	1.SB 2.PLA	None	7	All-male	27.1(SD:5.1)	175.8(SD:5.7)(cm)	72.2(SD:10.3)	None
39	N. Gaamouri	2019	RCT	Tunisia	Taekwondo	1.PP 2.PLA	1.PP:11 2.PLA:12	23	Males: 12 Females: 11	21.91(SD:1.22)	1.64(SD:0.03)(m)	67.34(SD:17.26)	BMI: 22.77(SD:5.54)
40	G. Fontani	2009	RCT	Italy	Karate	1.O3FA_PC(2.25 g + 10 mg) 2.PLA	1.O3FA_PC:10 2.PLA:8	18	Males: 12 Female: 6	O3FA_PC: 39 (SD: 9) PLA: 34 (SD: 9)	Not mentioned	Not mentioned	Not mentioned
Continued													

No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
41	A. Filip-Stachnik	2021	Cross-over design	Poland	Judo	1.CAF(2.7 mg/kg) 2.CAF(5.4 mg/kg) 3.PLA	Not mentioned	9	All-male	23.7(SD:4.4)	174.3(SD:4.0)(cm)	73.5(SD:7.4)	Body fat (%): 11.1(SD:4.0)
42	L. C. Felippe	2016	RCT	Brazil	Judo	1.CAF 2.SB 3.CAF_SB 4.PLA	Not mentioned	10	All-male	23(SD:5)	169.4(SD:6.1)(cm)	66.0(SD:5.3)	Body fat (%): 6.9(SD:2.7)
43	K. Durkalec-Michalski	2018	RCT	Poland	Wrestling	1.SB 2.PLA	1.SB:29 2.PLA:20	49	Males: 31 Females: 18	SB: 19(SD:4) PLA: 18 (SD: 4)	SB: 173 (SD: 9) (cm) PLA: 171 (SD: 7) (cm)	None	None
44	K. Durkalec-Michalski	2019	Cross-over design	Poland	Judo	1. CAF (3, 6, or 9 mg/kg body weight) 2.PLA	Not mentioned	22	All-male	21.7(SD:3.7)	178(SD:7)(cm)	76.4(SD:11.1)	BMI: 24.0(SD:2.1)
45	P. Drid	2016	Cross-over design	Serbia	Judo	1.HRW 2.PLA	Not mentioned	8	All-female	21.4(SD:2.2)	168.8(SD:7.2)(cm)	67.9(SD:11.0)	None
46	T. Donovan	2012	RCT	United Kingdom	Boxing	1.BA 2.PLA	1.BA:8 2.PLA:8	16	Not mentioned	25(SD:4)	1.74(SD:0.07)(m)	78.4(SD:7.6)	None
47	F. J. Diaz-Lara	2016	Cross-over design	Spain	Jiu-Jitsu	1.CAF 2.PLA	Not mentioned	14	All-male	29.2(SD: 3.3)	173.8(SD: 6.2)(cm)	71.3(SD: 9.1)	Body fat(%): 7.5(SD: 1.5) Body muscle mass%: 50.6(SD: 3.3)
48	S. Delleli	2023	Cross-over design	Tunisia	Taekwondo	1.CAF 2.PLA 3.CG	Not mentioned	16	All-male	18.25(SD:0.75)	182(SD:6.84)(cm)	60.92(SD:8.96)	None
49	G. V. de Oliveira	2018	Cross-over design	Brazil	Jiu-Jitsu	1.BRT 2.PLA	Not mentioned	12	All-male	29(SD: 9)	173(SD: 69)(cm)	81.3(SD: 10.1)	BMI: 26.3(SD: 2.7)
50	A. P. de Azevedo	2019	Cross-over design	Brazil	Mixed martial arts	1.CAF 2.PLA	Not mentioned	11	All-male	27.6(SD:4.3)	None	83.5(SD:7.8)	None
51	C. de Andrade Kratz	2016	RCT	Brazil	Judo	1.BA(6.4 g/day) 2.PLA	BA:12 Placebo:11	23	All-male	BA: 17(SD:2) Placebo: 19(SD:3)	None	BA: 74.2(SD:11.6) Placebo: 71.5(SD:10.7)	None
52	G. Danković	2022	Cross-over design	Serbia	Judo	1.SB(0.3 g/kg body weight) 2.PLA	Not mentioned	10	All-male	20(SD:2.1)	180.18(SD:8.11)(cm)	85.24(SD:23.17)	BMI: 25.2(SD:3.4)

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No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
53	J. Chycki	2021	RCT	Poland	Judo	1.SB 2.PLA	1.SB:8 2.PLA:8	16	All-male	SB: 24.3(SD:0.5) PLA: 23.2(SD:1.1)	SB: 181.0(SD:2.3)(cm) PLA: 178(SD:2.0)(cm)	SB: 81.0(SD:2.4) PLA: 84.2(SD:3.0)	None
54	J. Chycki	2018	RCT	Poland	Combat sport	1.HAW 2.PLA	1.HAW:8 2.PLA:8	16	All-male	HAW: 22.7(SD:3.2) PLA: 22.4(SD:2.8)	HAW: 181.2(SD:2.1)(cm) PLA: 178.3(SD:4.9)(cm)	HAW: 81.8(SD:3.2) PLA: 79.2(SD:2.6)	Body fat(%): HAW: 10.2(SD:2.1) PLA: 10.8(SD:2.4)
55	C. Chryssanthopoulos	2020	RCT	Greece	Fencing	1.CHO_E 2.PLA	Not mentioned	16	Males: 12 Females: 4	21.4(SE:0.2)	178(SE:2)(cm)	74.6(SE:3.3)	BMI: 23.4(SE:0.8) % body fat: 15.1(SE:1.4)
56	C. C. Chou	2018	RCT	Taiwan	Taekwondo	1.VITC_VITE 2.PLA	1.VITC_VITE:9 2.PLA:9	18	All-male	VITC_VITE: 21.0(SE:0.3) PLA: 21.3(SE:0.6)	VITC_VITE: 175.8(SE:2.1)(cm) PLA: 178.1(SE:2.7)(cm)	VITC_VITE: 67.9(SE:3.0) PLA: 71.5(SE:3.1)	BMI: VITC_VITE: 21.9(SE:0.7) PLA: 22.4(SE:0.5)
57	C. H. Chiu	2022	Cross-over design	Taiwan	Taekwondo	1.CHO 2.PLA	Not mentioned	13	Not mentioned	20.9(SD:1.0)	176.7(SD:4.6)(cm)	69.8(SD:6.9)	Body fat (%): 11.6(SD:3.8)
58	I. F. Chen	2016	Cross-over design	Taiwan	Taekwondo	1.BCAA_ARG_CIT(0.17 g/kg BCAA, 0.05 g/kg arginine and 0.05 g/kg citrulline) 2.PLA	Not mentioned	12	All-male	20.0(SD:0.8)	1.77(SD:0.04)(m)	66.9(SD:5.0)	BMI: 21.29(SD:0.93)
59	K. E. O. Carmo	2021	Cross-over design	Brazil	Judo	1.CAF 2.PLA	Not mentioned	8	Not mentioned	21.4(SD:2.0)	1.8(SD:0.1)(m)	83.6(SD:15.2)	Body fat (%): 17.9(SD:7.0)
60	C. J. Brito	2011	Cross-over design	Brazil	Judo	1.CHO 2.PLA	Not mentioned	15	All-male	22.1(SD:2.1)	177.5(SD:5.2)(m)	78.4(SD:8.9)	Body fat (%): 17.2(SD:3.3)
61	L. Bottoms	2013	Cross-over design	United Kingdom	Fencing	1.CAF 2.PLA	Not mentioned	11	Males: 7 Females: 4	33(SD:6.5)	1.77(SD:0.09)(m)	76.3(SD:14.3)	None
62	M. S. D. S. Athayde	2018	Cross-over design	Brazil	Judo	1.CAF 2.PLA	Not mentioned	14	All-male	22.5(SD:7.1)	172.9(SD:4.2)(cm)	76.6(SD:12.7)	Body fat (%): 12.9(SD:9.9)

Continued

No.	First author	Years of publication	Study design	Country or region of the author	Type of combat skill	Intervention type	Number of cases	Total population	Gender	Age (years)	Height	Weight (kg)	BMI or body fat(%)
63	G. G. Artioli	2007	Cross-over design	Brazil	Judo	1.SB 2.PLA	Protocol: SJFT: 9 Wingate: 14	23	Not mentioned	Protocol: SJFT: 21.5 (SD:3) Wingate: 19.3 (SD: 2.4)	Protocol: SJFT: 170.5 (SD: 6) (cm) Wingate: 175.8 (SD: 6.9) (cm)	Protocol: SJFT: 68.7 (SD: 7.7) Wingate: 77.9 (SD: 11.1)	Body fat (%): Protocol: SJFT: 6 (SD: 1.5) Wingate: 8.7 (SD: 1.7)
64	N. R. Antoniett	2021	Cross-over design	Brazil	Taekwondo	1.BRT 2.PLA	Not mentioned	12	All-male	26.8(SD:8.8)	1.8(SD:0.1)(m)	77.8(SD:11.7)	BMI: 25.3(SD:3.2) Body fat(%): 10.0(SD:5.3)
65	M. Aedma	2015	Cross-over design	Estonia	Wrestling Jiu Jitsu	1.SC 2.PLA	Not mentioned	11	Not mentioned	25.9 (SD:6.2)	1.80 (SD:0.03)(m)	80.1 (SD:8.9)	Not mentioned
66	M. Aedma	2013	Cross-over design	Estonia	Wrestling Jiu Jitsu	1.CAF 2.PLA	Not mentioned	14	Not mentioned	25.3 (SD:4.9)	178.9(SD:5.4)(cm)	77.8(SD:6.1)	Not mentioned
67	M. Souissi	2012	RCT	Tunisia	Judo	1.CAF 2.PLA	Not mentioned	12	Not mentioned	21.08 (SD:1.16)	1.76 (SD:6.57)(m)	83.75 (SD:20.2)	Not mentioned

Table 1. Characteristics of studies included in the systematic review. Data are presented as mean ± SD or mean ± SEM. *RCT* randomized controlled trial, *PLA* placebo, *CG* control group, *BMI* body mass index, *SJFT* special judo fitness test, *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_ARG_CIT* branched-chain amino acids + arginine + citrulline, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CM* citrulline malate, *CR* Creatine, *CR_SB* creatine + sodium bicarbonate, *CRM* Creatine malate, *HMB* beta-hydroxy-beta-methylbutyrate, HRW hydrogen-rich water, *PP* polyphenol, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine, SC sodium citrate, *VITC_VITE* vitamin C + vitamin E, *CoQ10* coenzyme Q10, *VITD* vitamin D, *VITD_PB* vitamin D + probiotics, *O3FA_PC* omega-3 fatty acids + policosanol, *CHO_E* carbohydrate + electrolyte, *HAW* highly alkaline water.

In 67 included studies, we examined the benefits of 26 different dietary supplements for elite combat sports athletes. Among these, caffeine emerged as the most frequently studied dietary supplement, with 24 studies focusing on caffeine (CAF) alone[42,44,46,47,49,50,52,54,56,57,60,64,65,67,69,70,78,80,84,85,89,95,99,102] or sodium bicarbonate + caffeine (SB_CAF)[65,89]. Thirteen studies explored sodium bicarbonate (SB) alone[41,45,48,55,65,66,73,74,81,86,89,96] or beta-alanine + sodium bicarbonate (BA_SB)[41], creatine + sodium bicarbonate (CR_SB)[45], and highly alkaline water (HAW)[100]. Six studies investigated beta-alanine (BA) alone[41,53,62,72,94,98]. Another six studies delved into carbohydrate (CHO) alone, carbohydrate + electrolyte (CHO_E)[39,61,76,79,88,101]or branched-chain amino acids + carbohydrate + arginine (BCAA_CHO_ARG)[61]. Arginine (ARG)[36,40,58] and beetroot juice (BRT)[59,71,82] were reported in three studies, respectively. Two studies examined the supplementation of vitamin C + vitamin E (VITC_VITE)[75,92]. Similarly, two studies explored vitamin D (VITD) alone or vitamin D + probiotics (VITD_PB)[90,91]. The remaining studies investigated Antilactate (ANT)[51], citrulline malate (CM)[38], creatine (CR)[45], Coenzyme Q10 (CoQ10)[87,93], creatine malate (CRM)[43], beta-hydroxy-beta-methylbutyrate (HMB)[37], hydrogen-rich water (HRW)[68], omega-3 fatty acids + policosanol (O3FA_PC)[97], polyphenol (PP)[63], sodium citrate (SC)[83], and branched-chain amino acids + arginine + citrulline (BCAA_ARG_CIT)[77], respectively.

To reveal the advantages of different dietary supplements for elite combat athletes, this study conducted a network meta-analysis of the following outcome measures: rating of perceived exertion[38,39,41,42,46,47,49,50,53–57,64,65,67,70,73,76,78,79,81,83,84],final heart rate[36,42,43,46,52–54,56,57,59,63,64,67,68,75,76,78,79,82–84], blood lactate concentration [36,38,40–44,46,48,51,53–58,60–62,64–66,68,71–75,77,78,80–84], mean power[37,41,42,44,45,51,58,59,61,62,66,74,76,81,83–85], peak power[37,41,42,44,45,51,58,61,66,74,76,81,83–85], number of throws[38,43,52,57,64–67,72,78,81], special judo fitness test index[38,43,52,53,57,64,67,68], Taekwondo-number of kicks[45,49,50,70,76], number of attacks[46,47,54,55,67,80], and grip streng th[39,56,60,69,73,80].

In terms of countries and regions, 19 studies were carried out in Brazil, 9 studies in Poland, 7 studies in Taiwan, 6 studies in Tunisia, 5 studies in Spain and the United Kingdom, 4 studies in Iran, 2 studies in Estonia, Japan, and Serbia, 1 study in Hong Kong, North Cyprus, Italy, Republic of Korea, Saudi Arabia, and Greece, respectively.

Risk of bias in studies

Out of the 67 randomized controlled trials we included, 64 provided a clear description of the randomization component in the sequence generation process. Two studies[62,101] outlined nonrandom components, while one study[39] lacked sufficient information to justify the generation of random sequences. Nineteen studies[36,37,39,40,45,51,53,58,62,74,76,85,88,92,97,98,100–102] did not offer enough details to determine if reasonable allocation concealment was performed, but the remaining studies implemented reasonable allocation concealment methods. Thirteen studies[36,37,39,40,45,51,53,58,62,85,97,100,101] failed to report information regarding blinding, whereas the other studies indicated that blinding was implemented. Seven studies[46,52,60,64,69,86,89] ensured the blinding evaluation of outcomes, while others did not specify this aspect. Two studies[66,67] experienced a high number of participants lost to follow-up, whereas the remaining studies were free of lost-to-follow-up bias. All studies were devoid of reporting bias and other biases. Detailed results can be found in Figs. 2 and 3.

Meta-analysis

Rating of perceived exertion

Twenty-four studies reported on the effects of different dietary supplements on the rating of perceived exertion in elite combat athletes, involving eight different dietary supplements, mainly CAF, SB, CHO, and SB_CAF, with other supplements explored in only a small number of studies (Fig. 4). The results from the meta-analysis on the consistency model indicated that, when compared to a placebo, no supplement demonstrated a statistically significant improvement in the rating of perceived exertion (Figure S1 and Table 2). According to the SUCRA rankings, BA_SB (SUCRA = 87.4%), SC (SUCRA = 57.8%), and BA (SUCRA = 55.7%) were the top three in terms of improving the rating of perceived exertion (Figure S2). The overall heterogeneity was low ($I^2 = 0\%$),

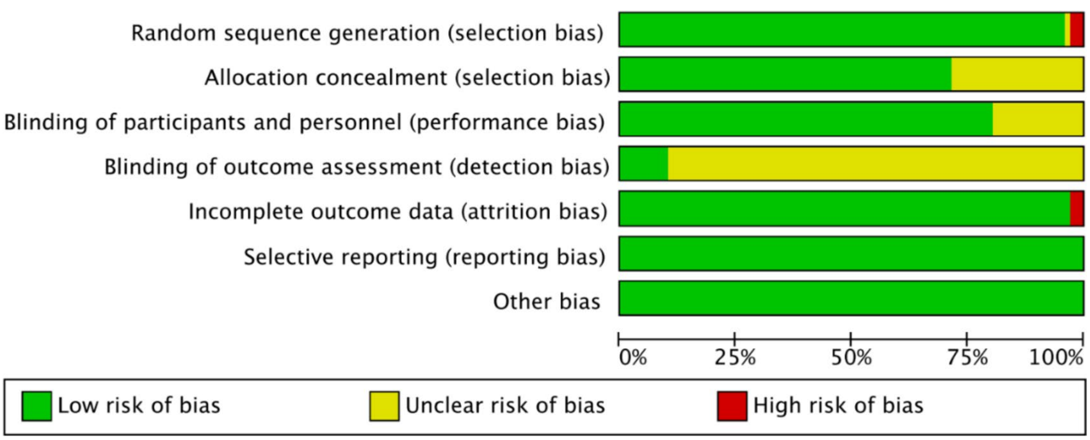

Fig. 2. Risk of bias graph.

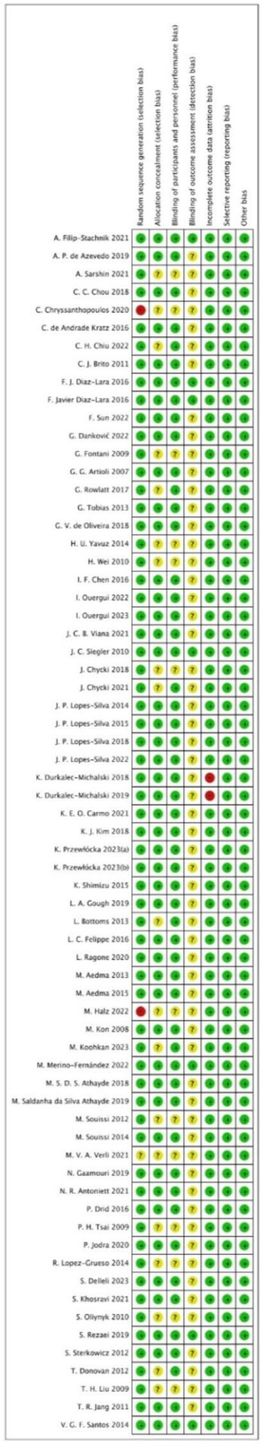

Fig. 3. Risk of bias summary.

indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Funnel plot did not provide evidence for apparent publication bias (Figure S3).

Final heart rate

Twenty-one studies reported on the effects of dietary supplements on the final heart rate of elite combat athletes, involving 10 different dietary supplements, mainly CAF, CHO, VITC_VITE and SC, with other supplements explored in only a small number of studies (Fig. 5). The results of the meta-analysis utilizing the consistency

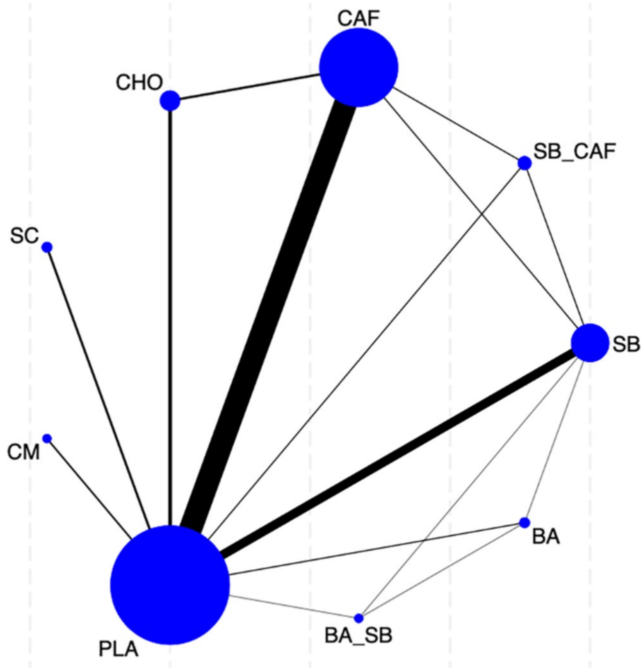

Fig. 4. Network diagram of the efficacy of different dietary supplements in improving the rating of perceived exertion. *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *CAF* caffeine, *CHO* carbohydrate, *CM* citrulline malate, *PLA* placebo, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine, *SC* sodium citrate.

	BA	BA_SB	CAF	CHO	CM	PLA	SB	SB_CAF	SC
BA	BA	− 0.58 (− 2.04, 0.83)	0.15 (− 0.79, 1.09)	0.22 (− 0.76, 1.19)	0.04 (− 1.04, 1.12)	0.27 (− 0.66, 1.19)	0.13 (− 0.83, 1.08)	0.09 (− 1.08, 1.27)	0.03 (− 1.02, 1.06)
BA_SB	0.58 (− 0.83, 2.04)	BA_SB	0.73 (− 0.35, 1.84)	0.8 (− 0.33, 1.95)	0.63 (− 0.59, 1.88)	0.85 (− 0.22, 1.95)	0.71 (− 0.38, 1.85)	0.67 (− 0.61, 1.98)	0.61 (− 0.57, 1.81)
CAF	− 0.15 (− 1.09, 0.79)	− 0.73 (− 1.84, 0.35)	CAF	0.07 (− 0.25, 0.37)	− 0.11 (− 0.69, 0.49)	0.12 (− 0.03, 0.27)	− 0.02 (− 0.31, 0.28)	− 0.06 (− 0.78, 0.65)	− 0.12 (− 0.62, 0.38)
CHO	− 0.22 (− 1.19, 0.76)	− 0.8 (− 1.95, 0.33)	− 0.07 (− 0.37, 0.25)	CHO	− 0.17 (− 0.82, 0.49)	0.06 (− 0.25, 0.37)	− 0.08 (− 0.48, 0.31)	− 0.13 (− 0.9, 0.64)	− 0.19 (− 0.75, 0.38)
CM	− 0.04 (− 1.12, 1.04)	− 0.63 (− 1.88, 0.59)	0.11 (− 0.49, 0.69)	0.17 (− 0.49, 0.82)	CM	0.23 (− 0.36, 0.8)	0.09 (− 0.55, 0.71)	0.05 (− 0.87, 0.95)	− 0.01 (− 0.76, 0.73)
PLA	− 0.27 (− 1.19, 0.66)	− 0.85 (− 1.95, 0.22)	− 0.12 (− 0.27, 0.03)	− 0.06 (− 0.37, 0.25)	− 0.23 (− 0.8, 0.36)	PLA	− 0.14 (− 0.39, 0.11)	− 0.18 (− 0.89, 0.52)	− 0.24 (− 0.72, 0.23)
SB	− 0.13 (− 1.08, 0.83)	− 0.71 (− 1.85, 0.38)	0.02 (− 0.28, 0.31)	0.08 (− 0.31, 0.48)	− 0.09 (− 0.71, 0.55)	0.14 (− 0.11, 0.39)	SB	− 0.04 (− 0.79, 0.7)	− 0.1 (− 0.64, 0.43)
SB_CAF	− 0.09 (− 1.27, 1.08)	− 0.67 (− 1.98, 0.61)	0.06 (− 0.65, 0.78)	0.13 (− 0.64, 0.9)	− 0.05 (− 0.95, 0.87)	0.18 (− 0.52, 0.89)	0.04 (− 0.7, 0.79)	SB_CAF	− 0.06 (− 0.9, 0.78)
SC	− 0.03 (− 1.06, 1.02)	− 0.61 (− 1.81, 0.57)	0.12 (− 0.38, 0.62)	0.19 (− 0.38, 0.75)	0.01 (− 0.73, 0.76)	0.24 (− 0.23, 0.72)	0.1 (− 0.43, 0.64)	0.06 (− 0.78, 0.9)	SC

Table 2. League table of the efficacy of different dietary supplements in improving the rating of perceived exertion. *BA* beta-alanine, BA_SB beta-alanine + sodium bicarbonate, *CAF* caffeine, *CHO* carbohydrate, *CM* citrulline malate, *PLA* placebo, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine, SC sodium citrate.

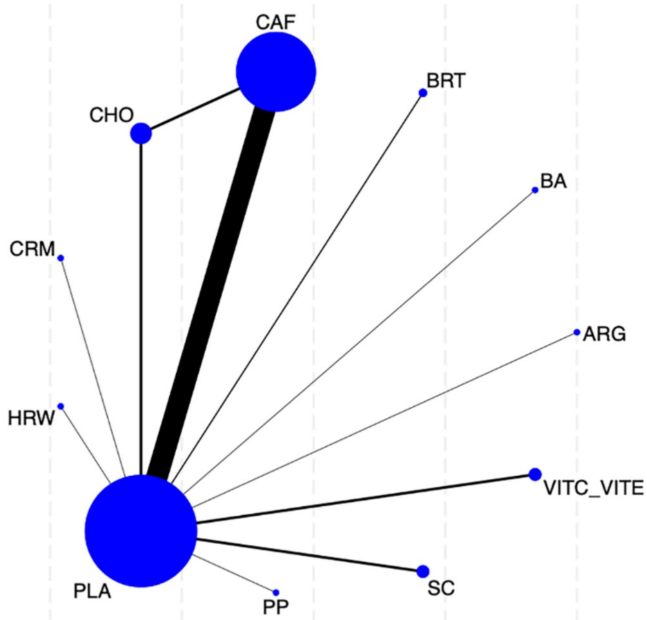

Fig. 5. Network diagram of the efficacy of different dietary supplements in improving final heart rate. *ARG* arginine, *BA* beta-alanine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CRM* creatine malate, *PLA* placebo, *PP* polyphenol, *SC* sodium citrate, *VITC_VITE* vitamin C + vitamin E.

	ARG	BA	BRT	CAF	CHO	CRM	PLA	PP	SC	VITC_VITE
ARG	ARG	− 0.65 (− 2.65, 1.51)	− 0.17 (− 1.32, 0.92)	− 0.13 (− 1.15, 0.81)	− 0.45 (− 1.5, 0.52)	− 0.73 (− 2.43, 0.85)	− 0.4 (− 1.39, 0.54)	− 0.69 (− 1.92, 0.58)	− 0.67 (− 1.72, 0.34)	− 0.92 (− 2.01, 0.13)
BA	0.65 (− 1.51, 2.65)	BA	0.43 (− 1.48, 2.28)	0.49 (− 1.42, 2.26)	0.19 (− 1.77, 1.94)	− 0.12 (− 2.26, 2.07)	0.23 (− 1.69, 1.99)	− 0.04 (− 2.09, 1.87)	− 0.04 (− 1.96, 1.74)	− 0.3 (− 2.26, 1.53)
BRT	0.17 (− 0.92, 1.32)	− 0.43 (− 2.28, 1.48)	BRT	0.05 (− 0.48, 0.58)	− 0.27 (− 0.84, 0.36)	− 0.55 (− 1.94, 0.83)	− 0.21 (− 0.72, 0.3)	− 0.49 (− 1.49, 0.47)	− 0.48 (− 1.15, 0.17)	**− 0.74 (− 1.45, − 0.03)**
CAF	0.13 (− 0.81, 1.15)	− 0.49 (− 2.26, 1.42)	− 0.05 (− 0.58, 0.48)	CAF	**− 0.32 (− 0.6, − 0.01)**	− 0.59 (− 1.92, 0.65)	**− 0.27 (− 0.41, − 0.12)**	− 0.53 (− 1.39, 0.27)	**− 0.53 (− 0.98, − 0.07)**	**− 0.78 (− 1.3, − 0.28)**
CHO	0.45 (− 0.52, 1.5)	− 0.19 (− 1.94, 1.77)	0.27 (− 0.36, 0.84)	**0.32 (0.01, 0.6)**	CHO	− 0.27 (− 1.63, 1.07)	0.06 (− 0.24, 0.33)	− 0.21 (− 1.15, 0.65)	− 0.22 (− 0.72, 0.32)	− 0.46 (− 1.06, 0.08)
CRM	0.73 (− 0.85, 2.43)	0.12 (− 2.07, 2.26)	0.55 (− 0.83, 1.94)	0.59 (− 0.65, 1.92)	0.27 (− 1.07, 1.63)	CRM	0.33 (− 0.91, 1.64)	0.06 (− 1.44, 1.58)	0.07 (− 1.26, 1.45)	− 0.2 (− 1.57, 1.24)
PLA	0.4 (− 0.54, 1.39)	− 0.23 (− 1.99, 1.69)	0.21 (− 0.3, 0.72)	**0.27 (0.12, 0.41)**	− 0.06 (− 0.33, 0.24)	− 0.33 (− 1.64, 0.91)	PLA	− 0.27 (− 1.12, 0.53)	− 0.27 (− 0.69, 0.17)	**− 0.52 (− 0.99, − 0.05)**
PP	0.69 (− 0.58, 1.92)	0.04 (− 1.87, 2.09)	0.49 (− 0.47, 1.49)	0.53 (− 0.27, 1.39)	0.21 (− 0.65, 1.15)	− 0.06 (− 1.58, 1.44)	0.27 (− 0.53, 1.12)	PP	0 (− 0.92, 0.94)	− 0.25 (− 1.2, 0.72)
SC	0.67 (− 0.34, 1.72)	0.04 (− 1.74, 1.96)	0.48 (− 0.17, 1.15)	**0.53 (0.07, 0.98)**	0.22 (− 0.32, 0.72)	− 0.07 (− 1.45, 1.26)	0.27 (− 0.17, 0.69)	0 (− 0.94, 0.92)	SC	− 0.25 (− 0.9, 0.38)
VITC_VITE	0.92 (− 0.13, 2.01)	0.3 (− 1.53, 2.26)	**0.74 (0.03, 1.45)**	**0.78 (0.28, 1.3)**	0.46 (− 0.08, 1.06)	0.2 (− 1.24, 1.57)	**0.52 (0.05, 0.99)**	0.25 (− 0.72, 1.2)	0.25 (− 0.38, 0.9)	VITC_VITE

Table 3. League table of the efficacy of different dietary supplements in improving final heart rate. Significant values are in bold. *ARG* arginine, *BA* beta-alanine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CRM* creatine malate, *PLA* placebo, *PP* polyphenol, *SC* sodium citrate, *VITC_VITE* vitamin C + vitamin E.

model indicated that, in comparison to the placebo, supplementation with CAF alone (SMD: 0.27, 95% CrI: 0.12, 0.41) was significantly associated with an increase in final heart rate (Figure S4 and Table 3). According to the SUCRA rankings, CAF (SUCRA = 81.6%), ARG (SUCRA = 78.6%), and BRT (SUCRA = 73.1%) were identified as the top three interventions for enhancing final heart rate (Figure S5). The overall heterogeneity was low (I^2 = 0%), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Funnel plot did not provide evidence for apparent publication bias (Figure S6).

Blood lactate concentrations

Thirty-five studies investigated the impact of various dietary supplements on blood lactate concentrations in elite combat athletes. The research encompassed sixteen different dietary supplements, primarily CAF, SB, BA, and SB_CAF. Other supplements were only minimally explored in a limited number of studies (Fig. 6). The meta-analysis results of the consistency model showed that, compared to placebo, supplementation of SB_CAF (SMD: 2.3, 95% CrI: 1.5, 3.2), CAF (SMD: 0.72, 95% CrI: 0.53, 0.93), BA (SMD: 0.58, 95% CrI: 0.079, 1.1), and SB (SMD: 0.54, 95% CrI: 0.30, 0.81) was associated with the statistically significant increase in blood lactate concentrations (Figure S7 and Table 4). Based on SUCRA ranking, SB_CAF (SUCRA = 99.9%), CAF (SUCRA = 85.0%), and BA (SUCRA = 74.7%) ranked the top three in enhancing blood lactate concentrations (Figure S8). The overall heterogeneity was moderate (I^2 = 35%), indicating some variability between the included studies, though the consistency of the network meta-analysis results remains reasonable. Importantly, funnel plot did not provide evidence for apparent publication bias (Figure S9).

Mean power

Seventeen studies investigated the impact of various dietary supplements on mean power in elite combat athletes, examining 13 different supplements, primarily SB, BA, and BA_SB. Other supplements were only minimally explored in a few studies (Fig. 7). The results of the meta-analysis utilizing the consistency model indicated that, in comparison to placebo, the supplementation of CR_SB (SMD: 2.2, 95% CrI: 1.5, 3.1), CR (SMD: 1.0, 95% CrI: 0.38, 1.6), and SB (SMD: 0.42, 95% CrI: 0.18, 0.66) was significantly associated with an increase in mean power (Figure S10 and Table 5). According to the SUCRA rankings, CR_SB (SUCRA = 99.9%), CR (SUCRA = 90.1%), and SB (SUCRA = 75.4%) occupied the top three positions in enhancing mean power (Figure S11). The overall heterogeneity was low (I^2 = 0%), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Funnel plot did not provide evidence for apparent publication bias (Figure S12).

Peak power

Fifteen studies investigated the impact of dietary supplements on peak power in elite combat athletes, encompassing 12 different supplements, predominantly SB, BA, and BA_SB. Other supplements were examined in a limited number of studies (Fig. 8). The results of the meta-analysis for the consistency model indicated that, in comparison to placebo, the supplementation of CR_SB (SMD: 1.6, 95% CrI: 0.85, 2.3), CR (SMD: 1.1, 95% CrI: 0.45, 1.7), and SB (SMD: 0.35, 95% CrI: 0.11, 0.57) was significantly associated with an increase in peak power (Figure S13 and Table 6). According to the SUCRA ranking, CR_SB (SUCRA = 98.4%), CR (SUCRA = 91.9%), and SB (SUCRA = 70.4%) emerged as the top three interventions for enhancing peak power (Figure S14). The overall heterogeneity was low (I^2 = 0%), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Importantly, funnel plot did not provide evidence for apparent publication bias (Figure S15).

Special judo fitness test

Number of throws Eleven studies investigated the impact of various dietary supplements on the throwing performance of elite combat athletes, encompassing six different supplements: CAF, SB_CAF, SB, CRM, CM, and BA (Fig. 9). The results from the meta-analysis of the consistency model indicated that only the supplementation of CAF alone (SMD: 0.35, 95% CrI: 0.081, 0.61), in comparison to placebo, was linked to a statistically significant

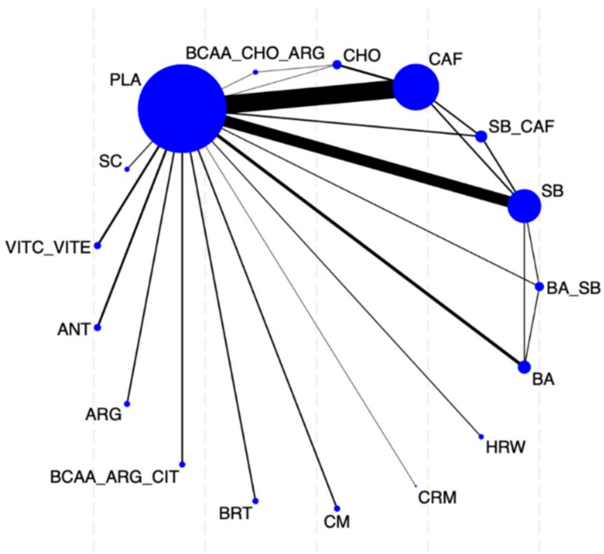

Fig. 6. Network diagram of the efficacy of different dietary supplements in improving blood lactate concentrations. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_ARG_CIT* branched-chain amino acids + arginine + citrulline, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CM* citrulline malate, *CRM* creatine malate, *HRW* hydrogen-rich water, *PLA* placebo, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine, *SC* sodium citrate, *VITC_VITE* vitamin C + E.

	ANT	ARG	BA	BA_SB	BCAA_ARG_CIT	BCAA_CHO_ARG	BRT	CAF	CHO	CM	CRM	HRW	PLA	SB	SB_CAF	SC	VITC_VITE
ANT	ANT	0.07 (− 0.79, 0.93)	0.39 (− 0.38, 1.17)	− 0.2 (− 1.18, 0.8)	− 0.21 (− 1.06, 0.63)	0.29 (− 1, 1.58)	− 0.55 (− 1.4, 0.29)	0.54 (− 0.09, 1.17)	− 0.05 (− 0.81, 0.72)	− 0.1 (− 1.01, 0.78)	− 0.61 (− 2.17, 0.94)	− 0.52 (− 1.56, 0.5)	− 0.18 (− 0.78, 0.42)	0.36 (− 0.28, 1.01)	**2.18 (1.15, 3.2)**	0.41 (− 0.56, 1.37)	− 0.48 (− 1.3, 0.34)
ARG	− 0.07 (− 0.93, 0.79)	ARG	0.32 (− 0.47, 1.12)	− 0.27 (− 1.27, 0.74)	− 0.28 (− 1.15, 0.58)	0.22 (− 1.09, 1.51)	− 0.62 (− 1.49, 0.24)	0.47 (− 0.18, 1.13)	− 0.12 (− 0.91, 0.67)	− 0.18 (− 1.1, 0.72)	− 0.69 (− 2.25, 0.87)	− 0.59 (− 1.64, 0.43)	− 0.25 (− 0.87, 0.37)	0.29 (− 0.37, 0.97)	**2.1 (1.08, 3.14)**	0.33 (− 0.65, 1.31)	− 0.56 (− 1.39, 0.28)
BA	− 0.39 (− 1.17, 0.38)	− 0.32 (− 1.12, 0.47)	BA	− 0.58 (− 1.53, 0.35)	− 0.6 (− 1.39, 0.17)	− 0.09 (− 1.37, 1.15)	**− 0.94 (− 1.73, − 0.18)**	0.15 (− 0.39, 0.69)	− 0.44 (− 1.14, 0.25)	− 0.49 (− 1.35, 0.32)	− 1 (− 2.52, 0.5)	− 0.9 (− 1.9, 0.03)	**− 0.56 (− 1.08, − 0.07)**	− 0.03 (− 0.58, 0.53)	**1.79 (0.83, 2.74)**	0.02 (− 0.91, 0.92)	**− 0.87 (− 1.64, − 0.13)**
BA_SB	0.2 (− 0.8, 1.18)	0.27 (− 0.74, 1.27)	0.58 (− 0.35, 1.53)	BA_SB	− 0.01 (− 1.01, 0.96)	0.49 (− 0.92, 1.86)	− 0.36 (− 1.36, 0.63)	0.73 (− 0.09, 1.55)	0.15 (− 0.79, 1.07)	0.09 (− 0.96, 1.11)	− 0.42 (− 2.05, 1.21)	− 0.32 (− 1.48, 0.79)	0.02 (− 0.79, 0.8)	0.55 (− 0.27, 1.38)	**2.37 (1.24, 3.51)**	0.6 (− 0.49, 1.69)	− 0.29 (− 1.28, 0.68)
BCAA_ARG_CIT	0.21 (− 0.63, 1.06)	0.28 (− 0.58, 1.15)	0.6 (− 0.17, 1.39)	0.01 (− 0.96, 1.01)	BCAA_ARG_CIT	0.51 (− 0.78, 1.78)	− 0.34 (− 1.17, 0.5)	**0.75 (0.13, 1.39)**	0.16 (− 0.6, 0.94)	0.1 (− 0.8, 0.99)	− 0.4 (− 1.95, 1.14)	− 0.31 (− 1.34, 0.7)	0.04 (− 0.56, 0.63)	0.57 (− 0.06, 1.24)	**2.39 (1.39, 3.4)**	0.62 (− 0.35, 1.59)	− 0.27 (− 1.1, 0.55)
BCAA_CHO_ARG	− 0.29 (− 1.58, 1)	− 0.22 (− 1.51, 1.09)	0.09 (− 1.15, 1.37)	− 0.49 (− 1.86, 0.92)	− 0.51 (− 1.78, 0.78)	BCAA_CHO_ARG	− 0.84 (− 2.14, 0.44)	0.25 (− 0.91, 1.42)	− 0.34 (− 1.59, 0.91)	− 0.4 (− 1.72, 0.92)	− 0.91 (− 2.72, 0.94)	− 0.81 (− 2.23, 0.6)	− 0.47 (− 1.62, 0.68)	0.07 (− 1.09, 1.25)	**1.88 (0.5, 3.31)**	0.11 (− 1.25, 1.49)	− 0.77 (− 2.06, 0.49)
BRT	0.55 (− 0.29, 1.4)	0.62 (− 0.24, 1.49)	**0.94 (0.18, 1.73)**	0.36 (− 0.63, 1.36)	0.34 (− 0.5, 1.17)	0.84 (− 0.44, 2.14)	BRT	**1.09 (0.48, 1.73)**	0.5 (− 0.25, 1.28)	0.44 (− 0.46, 1.33)	− 0.06 (− 1.6, 1.48)	0.03 (− 0.99, 1.05)	0.37 (− 0.22, 0.97)	**0.91 (0.28, 1.58)**	**2.72 (1.73, 3.75)**	0.95 (0, 1.93)	0.07 (− 0.74, 0.89)
CAF	− 0.54 (− 1.17, 0.09)	− 0.47 (− 1.13, 0.18)	− 0.15 (− 0.69, 0.39)	− 0.73 (− 1.55, 0.09)	**− 0.75 (− 1.39, − 0.13)**	− 0.25 (− 1.42, 0.91)	**− 1.09 (− 1.73, − 0.48)**	CAF	− 0.59 (− 1.05, − 0.13)	− 0.64 (− 1.36, 0.04)	− 1.15 (− 2.6, 0.28)	**− 1.05 (− 1.93, − 0.22)**	**− 0.72 (− 0.93, − 0.52)**	− 0.18 (− 0.49, 0.14)	**1.64 (0.79, 2.48)**	− 0.13 (− 0.92, 0.64)	**− 1.02 (− 1.63, − 0.43)**
CHO	0.05 (− 0.72, 0.81)	0.12 (− 0.67, 0.91)	0.44 (− 0.25, 1.14)	− 0.15 (− 1.07, 0.79)	− 0.16 (− 0.94, 0.6)	0.34 (− 0.91, 1.59)	− 0.5 (− 1.28, 0.25)	**0.59 (0.13, 1.05)**	CHO	− 0.05 (− 0.9, 0.76)	− 0.56 (− 2.07, 0.94)	− 0.46 (− 1.45, 0.47)	− 0.12 (− 0.62, 0.35)	0.41 (− 0.13, 0.96)	**2.23 (1.28, 3.18)**	0.46 (− 0.44, 1.35)	− 0.43 (− 1.18, 0.31)
CM	0.1 (− 0.78, 1.01)	0.18 (− 0.72, 1.1)	0.49 (− 0.32, 1.35)	− 0.09 (− 1.11, 0.96)	− 0.1 (− 0.99, 0.8)	0.4 (− 0.92, 1.72)	− 0.44 (− 1.33, 0.46)	0.64 (− 0.04, 1.36)	0.05 (− 0.76, 0.9)	CM	− 0.51 (− 2.09, 1.08)	− 0.41 (− 1.48, 0.65)	− 0.07 (− 0.73, 0.6)	0.47 (− 0.23, 1.2)	**2.28 (1.23, 3.35)**	0.51 (− 0.48, 1.53)	− 0.37 (− 1.24, 0.5)
CRM	0.61 (− 0.94, 2.17)	0.69 (− 0.87, 2.25)	1 (− 0.5, 2.52)	0.42 (− 1.21, 2.05)	0.4 (− 1.14, 1.95)	0.91 (− 0.94, 2.72)	0.06 (− 1.48, 1.6)	1.15 (− 0.28, 2.6)	0.56 (− 0.94, 2.07)	0.51 (− 1.08, 2.09)	CRM	0.1 (− 1.56, 1.73)	0.43 (− 0.99, 1.86)	0.98 (− 0.47, 2.43)	**2.79 (1.16, 4.45)**	1.02 (− 0.59, 2.64)	0.13 (− 1.41, 1.66)
HRW	0.52 (− 0.5, 1.56)	0.59 (− 0.43, 1.64)	0.9 (− 0.03, 1.9)	0.32 (− 0.79, 1.48)	0.31 (− 0.7, 1.34)	0.81 (− 0.6, 2.23)	− 0.03 (− 1.05, 0.99)	**1.05 (0.22, 1.93)**	0.46 (− 0.47, 1.45)	0.41 (− 0.65, 1.48)	− 0.1 (− 1.73, 1.56)	HRW	0.34 (− 0.48, 1.18)	**0.88 (0.03, 1.77)**	**2.69 (1.53, 3.88)**	0.93 (− 0.2, 2.05)	0.04 (− 0.96, 1.05)
PLA	0.18 (− 0.42, 0.78)	0.25 (− 0.37, 0.87)	**0.56 (0.07, 1.08)**	− 0.02 (− 0.8, 0.79)	− 0.04 (− 0.63, 0.56)	0.47 (− 0.68, 1.62)	− 0.37 (− 0.97, 0.22)	**0.72 (0.52, 0.93)**	0.12 (− 0.35, 0.62)	0.07 (− 0.6, 0.73)	− 0.43 (− 1.86, 0.99)	− 0.34 (− 1.18, 0.48)	PLA	**0.54 (0.3, 0.8)**	**2.35 (1.53, 3.18)**	0.58 (− 0.18, 1.34)	− 0.31 (− 0.87, 0.26)
SB	− 0.36 (− 1.01, 0.28)	− 0.29 (− 0.97, 0.37)	0.03 (− 0.53, 0.58)	− 0.55 (− 1.38, 0.27)	− 0.57 (− 1.24, 0.06)	− 0.07 (− 1.25, 1.09)	**− 0.91 (− 1.58, − 0.28)**	0.18 (− 0.14, 0.49)	− 0.41 (− 0.96, 0.13)	− 0.47 (− 1.2, 0.23)	− 0.98 (− 2.43, 0.47)	**− 0.88 (− 1.77, − 0.03)**	**− 0.54 (− 0.8, − 0.3)**	SB	**1.81 (0.96, 2.67)**	0.04 (− 0.76, 0.83)	**− 0.84 (− 1.47, − 0.24)**
Continued																	

	ANT	ARG	BA	BA_SB	BCAA_ARG_CIT	BCAA_CHO_ARG	BRT	CAF	CHO	CM	CRM	HRW	PLA	SB	SB_CAF	SC	VITC_VITE
SB_CAF	**− 2.18 (− 3.2, − 1.15)**	**− 2.1 (− 3.14, − 1.08)**	**− 1.79 (− 2.74, − 0.83)**	**− 2.37 (− 3.51, − 1.24)**	**− 2.39 (− 3.4, − 1.39)**	**− 1.88 (− 3.31, − 0.5)**	**− 2.72 (− 3.75, − 1.73)**	**− 1.64 (− 2.48, − 0.79)**	**− 2.23 (− 3.18, − 1.28)**	**− 2.28 (− 3.35, − 1.23)**	**− 2.79 (− 4.45, − 1.16)**	**− 2.69 (− 3.88, − 1.53)**	**− 2.35 (− 3.18, − 1.53)**	**− 1.81 (− 2.67, − 0.96)**	SB_CAF	**− 1.77 (− 2.9, − 0.66)**	**− 2.66 (− 3.66, − 1.66)**
SC	− 0.41 (− 1.37, 0.56)	− 0.33 (− 1.31, 0.65)	− 0.02 (− 0.92, 0.91)	− 0.6 (− 1.69, 0.49)	− 0.62 (− 1.59, 0.35)	− 0.11 (− 1.49, 1.25)	− 0.95 (− 1.93, 0)	0.13 (− 0.64, 0.92)	− 0.46 (− 1.35, 0.44)	− 0.51 (− 1.53, 0.48)	− 1.02 (− 2.64, 0.59)	− 0.93 (− 2.05, 0.2)	− 0.58 (− 1.34, 0.18)	− 0.04 (− 0.83, 0.76)	**1.77 (0.66, 2.9)**	SC	− 0.89 (− 1.83, 0.05)
VITC_VITE	0.48 (− 0.34, 1.3)	0.56 (− 0.28, 1.39)	**0.87 (0.13, 1.64)**	0.29 (− 0.68, 1.28)	0.27 (− 0.55, 1.1)	0.77 (− 0.49, 2.06)	− 0.07 (− 0.89, 0.74)	**1.02 (0.43, 1.63)**	0.43 (− 0.31, 1.18)	0.37 (− 0.5, 1.24)	− 0.13 (− 1.66, 1.41)	− 0.04 (− 1.05, 0.96)	0.31 (− 0.26, 0.87)	**0.84 (0.24, 1.47)**	**2.66 (1.66, 3.66)**	0.89 (− 0.05, 1.83)	VITC_VITE

Table 4. League table of the efficacy of different dietary supplements in improving blood lactate concentrations. Significant values are in bold. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_ARG_CIT* branched-chain amino acids + arginine + citrulline, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CM* citrulline malate, *CRM* creatine malate, HRW hydrogen-rich water, *PLA* placebo, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine, *SC* sodium citrate, *VITC_VITE* vitamin C + E.

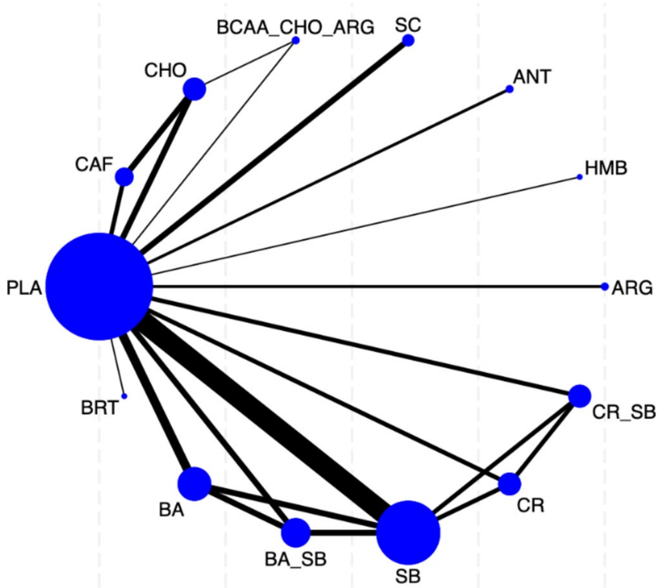

Fig. 7. Network diagram of the efficacy of different dietary supplements in improving mean power. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CR* creatine, *CR_SB* creatine + sodium bicarbonate, *HMB* beta-hydroxy-beta-methylbutyrate, *PLA* placebo, *SB* sodium bicarbonate, *SC* sodium citrate.

increase in the number of throws as shown in Figure S16 and Table 7. According to the SUCRA ranking, the top three interventions for increasing the number of throws were SB_CAF (SUCRA = 85.8%), BA (SUCRA = 78.2%), and SB (SUCRA = 59.6%) as illustrated in Figure S17. The overall heterogeneity was low ($I^2 = 0\%$), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Importantly, funnel plot did not provide evidence for apparent publication bias (Figure S18).

Special judo fitness test index Eight studies investigated the impact of various dietary supplements on the special judo fitness test index in elite combat athletes, exploring five different supplements: CAF, BA, CM, CRM, and HRW (Fig. 10). The results of the meta-analysis of the consistency model indicated that, when compared to placebo, no supplement demonstrated a statistically significant improvement in the special judo fitness test index (Figure S19 and Table 8). According to the SUCRA ranking, CM (SUCRA = 81.2%), BA (SUCRA = 73.6%), and HRW (SUCRA = 48.9%) were identified as the top three supplements for improving the special judo fitness test index (Figure S20). The overall heterogeneity was low ($I^2 = 0\%$), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Funnel plot did not provide evidence for apparent publication bias (Figure S21).

Taekwondo kick test - number of kicks
Five studies investigated the impact of various dietary supplements on the number of kicks in elite combat athletes. These studies encompassed five distinct supplements, namely CAF, SB, CR, CR_SB, and CHO (Fig. 11). The results of the meta-analysis for the consistency model indicated that, in comparison to the placebo, the supplementation with CAF alone (SMD: 1.4, 95% CrI: 0.19, 2.7) was the only intervention associated with a statistically significant increase in the number of kicks (Figure S22 and Table 9). According to the SUCRA ranking, CR_SB (SUCRA = 75.2%), CAF (SUCRA = 71.5%), and SB (SUCRA = 70.3%) were the top three interventions in promoting an increase in the number of kicks (Figure S23). The overall heterogeneity was low ($I^2 = 9\%$), indicating minimal variability between the included studies and supporting the consistency of the network meta-analysis results. Importantly, funnel plot did not provide evidence for apparent publication bias (Figure S24).

Simulated competition - number of attacks
Six studies investigated the impact of various dietary supplements on the number of attacks in elite combat athletes. The studies examined two different supplements, namely CAF and SB (Fig. 12). The meta-analysis results of the consistency model showed that, compared to placebo, no supplement was associated with the statistically significant increase in the number of attacks (Figure S25 and Table 10). Based on SUCRA values, the rankings were CAF (SUCRA = 78.4%) and SB (SUCRA = 49.6%) (Figure S26). The overall heterogeneity was low ($I^2 = 0\%$), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Importantly, funnel plot did not provide evidence for apparent publication bias (Figure S27).

	ANT	ARG	BA	BA_SB	BCAA_CHO_ARG	BRT	CAF	CHO	CR	CR_SB	HMB	PLA	SB	SC
ANT	ANT	− 0.14 (− 1.14, 0.83)	− 0.04 (− 0.91, 0.81)	− 0.2 (− 1.2, 0.69)	0.09 (− 1.08, 1.32)	− 0.01 (− 1.23, 1.14)	− 0.13 (− 0.95, 0.74)	− 0.11 (− 0.95, 0.73)	0.87 (− 0.11, 1.81)	**2.11 (1.06, 3.27)**	− 1.26 (− 2.93, 0.49)	− 0.14 (− 0.89, 0.59)	0.27 (− 0.5, 1.04)	− 0.22 (− 1.19, 0.65)
ARG	0.14 (− 0.83, 1.14)	ARG	0.1 (− 0.67, 0.87)	− 0.06 (− 0.87, 0.74)	0.25 (− 0.92, 1.35)	0.13 (− 0.89, 1.21)	0.01 (− 0.77, 0.76)	0.02 (− 0.72, 0.75)	**1 (0.11, 1.87)**	**2.24 (1.23, 3.34)**	− 1.12 (− 2.81, 0.66)	0 (− 0.64, 0.64)	0.42 (− 0.27, 1.09)	− 0.09 (− 0.86, 0.67)
BA	0.04 (− 0.81, 0.91)	− 0.1 (− 0.87, 0.67)	BA	− 0.17 (− 0.79, 0.49)	0.15 (− 0.9, 1.17)	0.03 (− 0.88, 0.97)	− 0.08 (− 0.66, 0.48)	− 0.07 (− 0.62, 0.47)	**0.9 (0.14, 1.65)**	**2.16 (1.3, 3.1)**	− 1.22 (− 2.86, 0.46)	− 0.1 (− 0.5, 0.31)	0.32 (− 0.14, 0.77)	− 0.19 (− 0.77, 0.41)
BA_SB	0.2 (− 0.69, 1.2)	0.06 (− 0.74, 0.87)	0.17 (− 0.49, 0.79)	BA_SB	0.3 (− 0.75, 1.38)	0.2 (− 0.77, 1.16)	0.07 (− 0.55, 0.77)	0.08 (− 0.53, 0.69)	**1.07 (0.27, 1.84)**	**2.32 (1.42, 3.28)**	− 1.04 (− 2.72, 0.64)	0.06 (− 0.44, 0.58)	0.48 (− 0.08, 1.07)	− 0.01 (− 0.65, 0.61)
BCAA_CHO_ARG	− 0.09 (− 1.32, 1.08)	− 0.25 (− 1.35, 0.92)	− 0.15 (− 1.17, 0.9)	− 0.3 (− 1.38, 0.75)	BCAA_CHO_ARG	− 0.08 (− 1.37, 1.17)	− 0.24 (− 1.24, 0.87)	− 0.23 (− 1.22, 0.9)	0.75 (− 0.37, 1.92)	**2.01 (0.8, 3.28)**	− 1.37 (− 3.17, 0.52)	− 0.25 (− 1.18, 0.72)	0.17 (− 0.81, 1.16)	− 0.33 (− 1.37, 0.74)
BRT	0.01 (− 1.14, 1.23)	− 0.13 (− 1.21, 0.89)	− 0.03 (− 0.97, 0.88)	− 0.2 (− 1.16, 0.77)	0.08 (− 1.17, 1.37)	BRT	− 0.13 (− 1.07, 0.8)	− 0.12 (− 1.04, 0.77)	0.86 (− 0.18, 1.87)	**2.13 (0.96, 3.26)**	− 1.24 (− 3.03, 0.5)	− 0.14 (− 1, 0.7)	0.28 (− 0.6, 1.21)	− 0.21 (− 1.18, 0.69)
CAF	0.13 (− 0.74, 0.95)	− 0.01 (− 0.76, 0.77)	0.08 (− 0.48, 0.66)	− 0.07 (− 0.77, 0.55)	0.24 (− 0.87, 1.24)	0.13 (− 0.8, 1.07)	CAF	0.01 (− 0.33, 0.35)	**1 (0.24, 1.71)**	**2.24 (1.39, 3.15)**	− 1.14 (− 2.72, 0.56)	− 0.02 (− 0.42, 0.39)	0.4 (− 0.06, 0.86)	− 0.09 (− 0.7, 0.49)
CHO	0.11 (− 0.73, 0.95)	− 0.02 (− 0.75, 0.72)	0.07 (− 0.47, 0.62)	− 0.08 (− 0.69, 0.53)	0.23 (− 0.9, 1.22)	0.12 (− 0.77, 1.04)	− 0.01 (− 0.35, 0.33)	CHO	**0.99 (0.26, 1.67)**	**2.22 (1.39, 3.12)**	− 1.14 (− 2.71, 0.54)	− 0.03 (− 0.38, 0.33)	0.4 (− 0.03, 0.8)	− 0.11 (− 0.66, 0.46)
CR	− 0.87 (− 1.81, 0.11)	**− 1 (− 1.87, − 0.11)**	**− 0.9 (− 1.65, − 0.14)**	**− 1.07 (− 1.84, − 0.27)**	− 0.75 (− 1.92, 0.37)	− 0.86 (− 1.87, 0.18)	**− 1 (− 1.71, − 0.24)**	**− 0.99 (− 1.67, − 0.26)**	CR	**1.27 (0.28, 2.29)**	− 2.13 (− 3.78, − 0.32)	**− 1 (− 1.61, − 0.38)**	− 0.59 (− 1.23, 0.07)	**− 1.09 (− 1.83, − 0.33)**
CR_SB	**− 2.11 (− 3.27, − 1.06)**	**− 2.24 (− 3.34, − 1.23)**	**− 2.16 (− 3.1, − 1.3)**	**− 2.32 (− 3.28, − 1.42)**	**− 2.01 (− 3.28, − 0.8)**	**− 2.13 (− 3.26, − 0.96)**	**− 2.24 (− 3.15, − 1.39)**	**− 2.22 (− 3.12, − 1.39)**	**− 1.27 (− 2.29, − 0.28)**	CR_SB	− 3.36 (− 5.16, − 1.59)	**− 2.25 (− 3.11, − 1.47)**	**− 1.83 (− 2.72, − 1.03)**	**− 2.34 (− 3.26, − 1.45)**
HMB	1.26 (− 0.49, 2.93)	1.12 (− 0.66, 2.81)	1.22 (− 0.46, 2.86)	1.04 (− 0.64, 2.72)	1.37 (− 0.52, 3.17)	1.24 (− 0.5, 3.03)	1.14 (− 0.56, 2.72)	1.14 (− 0.54, 2.71)	**2.13 (0.32, 3.78)**	**3.36 (1.59, 5.16)**	HMB	1.12 (− 0.49, 2.66)	1.54 (− 0.11, 3.11)	1.03 (− 0.66, 2.65)
PLA	0.14 (− 0.59, 0.89)	0 (− 0.64, 0.64)	0.1 (− 0.31, 0.5)	− 0.06 (− 0.58, 0.44)	0.25 (− 0.72, 1.18)	0.14 (− 0.7, 1)	0.02 (− 0.39, 0.42)	0.03 (− 0.33, 0.38)	**1 (0.38, 1.61)**	**2.25 (1.47, 3.11)**	− 1.12 (− 2.66, 0.49)	PLA	**0.42 (0.18, 0.66)**	− 0.08 (− 0.51, 0.35)
SB	− 0.27 (− 1.04, 0.5)	− 0.42 (− 1.09, 0.27)	− 0.32 (− 0.77, 0.14)	− 0.48 (− 1.07, 0.08)	− 0.17 (− 1.16, 0.81)	− 0.28 (− 1.21, 0.6)	− 0.4 (− 0.86, 0.06)	− 0.4 (− 0.8, 0.03)	0.59 (− 0.07, 1.23)	**1.83 (1.03, 2.72)**	− 1.54 (− 3.11, 0.11)	**− 0.42 (− 0.66, − 0.18)**	SB	**− 0.5 (− 1.04, − 0.02)**
SC	0.22 (− 0.65, 1.19)	0.09 (− 0.67, 0.86)	0.19 (− 0.41, 0.77)	0.01 (− 0.61, 0.65)	0.33 (− 0.74, 1.37)	0.21 (− 0.69, 1.18)	0.09 (− 0.49, 0.7)	0.11 (− 0.46, 0.66)	**1.09 (0.33, 1.83)**	**2.34 (1.45, 3.26)**	− 1.03 (− 2.65, 0.66)	0.08 (− 0.35, 0.51)	**0.5 (0.02, 1.04)**	SC

Table 5. League table of the efficacy of different dietary supplements in improving mean power. Significant values are in bold. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *BRT* beetroot juice, *CAF* caffeine, *CHO* carbohydrate, *CR* creatine, *CR_SB* creatine + sodium bicarbonate, *HMB* beta-hydroxy-beta-methylbutyrate, *PLA* placebo, *SB* sodium bicarbonate, *SC* sodium citrate.

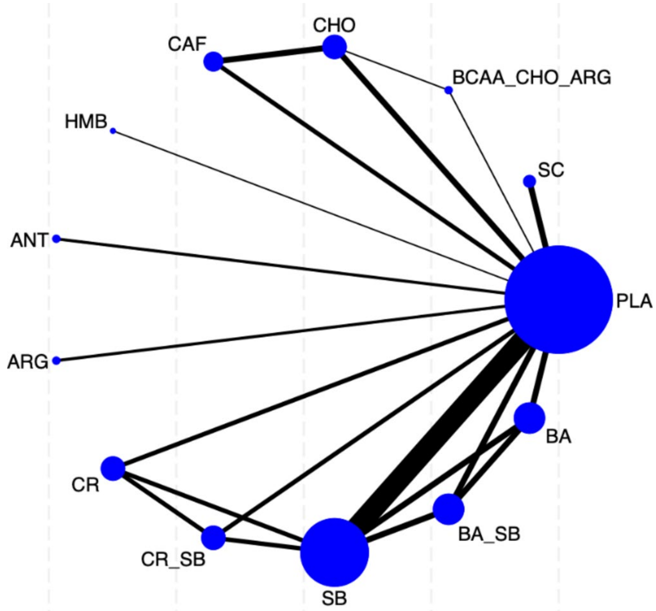

Fig. 8. Network diagram of the efficacy of different dietary supplements in improving peak power. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *CAF* caffeine, *CHO* carbohydrate, *CR* Creatine, *CR_SB* creatine + sodium bicarbonate, *HMB* beta-hydroxy-beta-methylbutyrate, *PLA* placebo, *SB* sodium bicarbonate, *SC* sodium citrate.

Grip strength
Six studies investigated the impact of various dietary supplements on grip strength in elite combat athletes, encompassing three distinct supplements: CAF, SB, and CHO (Fig. 13). The results of the meta-analysis pertaining to the consistency model indicated that, in comparison to a placebo, no supplement demonstrated a statistically significant increase in grip strength (Figure S28 and Table 11). According to SUCRA values, the rankings were as follows: SB (SUCRA = 90.3%), CAF (SUCRA = 71.2%), and CHO (SUCRA = 1.8%) (Figure S29). The overall heterogeneity was low ($I^2 = 0\%$), indicating no variability between the included studies and supporting a high level of consistency in the network meta-analysis results. Funnel plot did not provide evidence for apparent publication bias (Figure S30).

Subgroup analysis
We performed subgroup analyses of rating of perceived exertion, final heart rate, blood lactate concentration, mean power, and peak power by type of striking and grappling. The subgroup analysis results show that, for elite striking combat athletes, compared to placebo, the supplementation of SB (SMD: 0.69, 95% CrI: 0.11, 1.3) and CAF (SMD: 0.45, 95% CrI: 0.17, 0.73) was associated with the statistically significant improvement in blood lactate concentration; the supplementation of CR_SB (SMD: 2.2; 95% CrI: 1.4, 3.1), SB (SMD: 1.2, 95% CrI: 0.53, 1.9), and CR (SMD: 1.0, 95% CrI: 0.32, 1.7) was associated with the statistically significant increase in mean power; the supplementation of CR_SB (SMD: 1.6, 95% CrI: 0.17, 3.0) was associated with the statistically significant increase in peak power. However, in comparison to the placebo, no dietary supplements demonstrated a statistically significant improvement in the rating of perceived exertion and final heart rate among elite striking combat athletes. For elite grappling combat athletes, compared to the placebo, the supplementation of CAF (SMD: 0.39, 95% CrI: 0.20, 0.57) was linked to a statistically significant rise in final heart rate; the supplementation of SB_CAF (SMD: 2.4, 95% CrI: 1.4, 3.5), CAF (SMD: 0.93, 95% CrI: 0.60, 1.3), and SB (SMD: 0.60, 95% CrI: 0.24, 0.99) was correlated with statistically significant improvements in blood lactate concentration; the supplementation of SB was associated with a statistically significant increase in mean power (SMD: 0.31, 95% CrI: 0.063, 0.55) and peak power (SMD: 0.36, 95% CrI: 0.12, 0.61). Nonetheless, when compared to the placebo, no dietary supplements were identified to yield a statistically significant improvement in the rating of perceived exertion for elite grappling combat athletes (for detailed description, see Supplementary Material 4).

Overview of other combat sports
Among the 17 studies included in our systematic review, for boxing, SB was associated with a statistically significant increase in blood buffering capacity and punch efficiency compared with a placebo. It also helps restore acid-base balance, resulting in significant improvements in subsequent athletic performance[86,96]. Compared to placebo, BA was associated with a statistically significant improvement in lower extremity peak power and upper extremity power maintenance, punch performance, and blood lactate levels[94,98]. Compared to placebo, CAF was associated with a statistically significantly improvement in anaerobic exercise performance, subjective cognitive function, and emotional state[95]. In fencing, compared to a placebo, CAF helps maintain skills and reduce overall

	ANT	ARG	BA	BA_SB	BCAA_CHO_ARG	CAF	CHO	CR	CR_SB	HMB	PLA	SB	SC
ANT	ANT	-0.13 (-1.11, 0.83)	0.13 (-0.73, 1.01)	0.11 (-0.74, 0.98)	0.18 (-0.96, 1.38)	0.05 (-0.77, 0.88)	0.08 (-0.71, 0.88)	**1.06 (0.1, 1.99)**	**1.52 (0.49, 2.59)**	-1.12 (-2.91, 0.78)	-0.05 (-0.76, 0.69)	0.29 (-0.45, 1.07)	-0.15 (-0.98, 0.7)
ARG	0.13 (-0.83, 1.11)	ARG	0.26 (-0.53, 1.04)	0.25 (-0.53, 1.03)	0.31 (-0.81, 1.48)	0.18 (-0.58, 0.93)	0.22 (-0.5, 0.93)	**1.18 (0.3, 2.11)**	**1.67 (0.7, 2.57)**	-0.99 (-2.74, 0.84)	0.1 (-0.54, 0.71)	0.44 (-0.24, 1.1)	0 (-0.79, 0.74)
BA	-0.13 (-1.01, 0.73)	-0.26 (-1.04, 0.53)	BA	-0.01 (-0.65, 0.65)	0.06 (-1.04, 1.13)	-0.08 (-0.7, 0.51)	-0.04 (-0.6, 0.53)	**0.92 (0.09, 1.74)**	**1.4 (0.57, 2.23)**	-1.22 (-2.96, 0.48)	-0.17 (-0.63, 0.29)	0.18 (-0.34, 0.69)	-0.27 (-0.91, 0.36)
BA_SB	-0.11 (-0.98, 0.74)	-0.25 (-1.03, 0.53)	0.01 (-0.65, 0.65)	BA_SB	0.06 (-0.96, 1.13)	-0.07 (-0.7, 0.54)	-0.02 (-0.61, 0.56)	**0.94 (0.14, 1.74)**	**1.4 (0.56, 2.23)**	-1.22 (-2.94, 0.47)	-0.16 (-0.62, 0.3)	0.19 (-0.34, 0.7)	-0.26 (-0.9, 0.35)
BCAA_CHO_ARG	-0.18 (-1.38, 0.96)	-0.31 (-1.48, 0.81)	-0.06 (-1.13, 1.04)	-0.06 (-1.13, 0.96)	BCAA_CHO_ARG	-0.13 (-1.17, 0.87)	-0.09 (-1.11, 0.9)	0.89 (-0.27, 2)	**1.33 (0.15, 2.53)**	-1.29 (-3.17, 0.55)	-0.23 (-1.18, 0.71)	0.13 (-0.87, 1.08)	-0.34 (-1.36, 0.73)
CAF	-0.05 (-0.88, 0.77)	-0.18 (-0.93, 0.58)	0.08 (-0.51, 0.7)	0.07 (-0.54, 0.7)	0.13 (-0.87, 1.17)	CAF	0.04 (-0.28, 0.37)	**1.02 (0.21, 1.78)**	**1.48 (0.63, 2.3)**	-1.15 (-2.86, 0.53)	-0.09 (-0.47, 0.31)	0.26 (-0.2, 0.72)	-0.19 (-0.77, 0.37)
CHO	-0.08 (-0.88, 0.71)	-0.22 (-0.93, 0.5)	0.04 (-0.53, 0.6)	0.02 (-0.56, 0.61)	0.09 (− 0.9, 1.11)	− 0.04 (− 0.37, 0.28)	CHO	**0.97 (0.23, 1.71)**	**1.44 (0.62, 2.23)**	− 1.17 (− 2.89, 0.48)	− 0.13 (− 0.47, 0.21)	0.21 (− 0.19, 0.63)	− 0.23 (− 0.78, 0.33)
CR	**− 1.06 (− 1.99, − 0.1)**	**− 1.18 (− 2.11, − 0.3)**	**− 0.92 (− 1.74, − 0.09)**	**− 0.94 (− 1.74, − 0.14)**	− 0.89 (− 2, 0.27)	**− 1.02 (− 1.78, − 0.21)**	**− 0.97 (− 1.71, − 0.23)**	CR	0.47 (− 0.54, 1.45)	**− 2.17 (− 3.96, − 0.34)**	**− 1.1 (− 1.75, − 0.45)**	**− 0.76 (− 1.43, − 0.08)**	**− 1.2 (− 1.98, − 0.44)**
CR_SB	**− 1.52 (− 2.59, − 0.49)**	**− 1.67 (− 2.57, − 0.7)**	**− 1.4 (− 2.23, − 0.57)**	**− 1.4 (− 2.23, − 0.56)**	**− 1.33 (− 2.53, − 0.15)**	**− 1.48 (− 2.3, − 0.63)**	**− 1.44 (− 2.23, − 0.62)**	− 0.47 (− 1.45, 0.54)	CR_SB	**− 2.62 (− 4.41, − 0.87)**	**− 1.57 (− 2.27, − 0.85)**	**− 1.22 (− 1.95, − 0.45)**	**− 1.66 (− 2.48, − 0.83)**
HMB	1.12 (− 0.78, 2.91)	0.99 (− 0.84, 2.74)	1.22 (− 0.48, 2.96)	1.22 (− 0.47, 2.94)	1.29 (− 0.55, 3.17)	1.15 (− 0.53, 2.86)	1.17 (− 0.48, 2.89)	**2.17 (0.34, 3.96)**	**2.62 (0.87, 4.41)**	HMB	1.07 (− 0.59, 2.73)	1.42 (− 0.3, 3.07)	0.98 (− 0.76, 2.65)
PLA	0.05 (− 0.69, 0.76)	− 0.1 (− 0.71, 0.54)	0.17 (− 0.29, 0.63)	0.16 (− 0.3, 0.62)	0.23 (− 0.71, 1.18)	0.09 (− 0.31, 0.47)	0.13 (− 0.21, 0.47)	**1.1 (0.45, 1.75)**	**1.57 (0.85, 2.27)**	− 1.07 (− 2.73, 0.59)	PLA	**0.35 (0.11, 0.57)**	− 0.1 (− 0.53, 0.33)
SB	− 0.29 (− 1.07, 0.45)	− 0.44 (− 1.1, 0.24)	− 0.18 (− 0.69, 0.34)	− 0.19 (− 0.7, 0.34)	− 0.13 (− 1.08, 0.87)	− 0.26 (− 0.72, 0.2)	− 0.21 (− 0.63, 0.19)	**0.76 (0.08, 1.43)**	**1.22 (0.45, 1.95)**	− 1.42 (− 3.07, 0.3)	**− 0.35 (− 0.57, − 0.11)**	SB	− 0.44 (− 0.93, 0.05)
SC	0.15 (− 0.7, 0.98)	0 (− 0.74, 0.79)	0.27 (− 0.36, 0.91)	0.26 (− 0.35, 0.9)	0.34 (− 0.73, 1.36)	0.19 (− 0.37, 0.77)	0.23 (− 0.33, 0.78)	**1.2 (0.44, 1.98)**	**1.66 (0.83, 2.48)**	− 0.98 (− 2.65, 0.76)	0.1 (− 0.33, 0.53)	0.44 (− 0.05, 0.93)	SC

Table 6. League table of the efficacy of different dietary supplements in improving peak power. Significant values are in bold. *ANT* antilactate, *ARG* arginine, *BA* beta-alanine, *BA_SB* beta-alanine + sodium bicarbonate, *BCAA_CHO_ARG* branched-chain amino acids + carbohydrate + arginine, *CAF* caffeine, *CHO* carbohydrate, *CR* creatine, *CR_SB* creatine + sodium bicarbonate, *HMB* beta-hydroxy-beta-methylbutyrate, *PLA* placebo, *SB* sodium bicarbonate, *SC* sodium citrate.

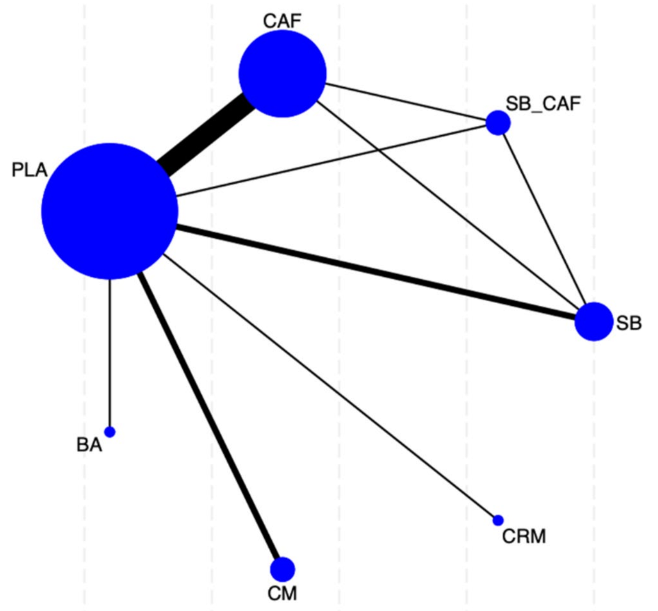

Fig. 9. Network diagram of the efficacy of different dietary supplements in enhancing the number of throws. *BA* beta-alanine, *CAF* caffeine, *CM* citrulline malate, *CRM* creatine malate, *PLA* placebo, *SB* sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine.

	BA	CAF	CM	CRM	PLA	SB	SB_CAF
BA	BA	− 0.47 (− 1.45, 0.48)	− 0.4 (− 1.48, 0.67)	**− 2.65 (− 4.59, − 0.71)**	− 0.82 (− 1.75, 0.1)	− 0.36 (− 1.41, 0.69)	0.19 (− 1.19, 1.54)
CAF	0.47 (− 0.48, 1.45)	CAF	0.07 (− 0.53, 0.69)	**− 2.18 (− 3.91, − 0.51)**	**− 0.35 (− 0.61, − 0.08)**	0.11 (− 0.44, 0.68)	0.66 (− 0.4, 1.71)
CM	0.4 (− 0.67, 1.48)	− 0.07 (− 0.69, 0.53)	CM	**− 2.26 (− 4.03, − 0.52)**	− 0.42 (− 0.97, 0.13)	0.04 (− 0.69, 0.78)	0.59 (− 0.58, 1.75)
CRM	**2.65 (0.71, 4.59)**	**2.18 (0.51, 3.91)**	**2.26 (0.52, 4.03)**	CRM	**1.84 (0.18, 3.53)**	**2.29 (0.58, 4.07)**	**2.85 (0.89, 4.81)**
PLA	0.82 (− 0.1, 1.75)	**0.35 (0.08, 0.61)**	0.42 (− 0.13, 0.97)	**− 1.84 (− 3.53, − 0.18)**	PLA	0.46 (− 0.02, 0.95)	1.01 (− 0.01, 2.01)
SB	0.36 (− 0.69, 1.41)	− 0.11 (− 0.68, 0.44)	− 0.04 (− 0.78, 0.69)	**− 2.29 (− 4.07, − 0.58)**	− 0.46 (− 0.95, 0.02)	SB	0.55 (− 0.59, 1.66)
SB_CAF	− 0.19 (− 1.54, 1.19)	− 0.66 (− 1.71, 0.4)	− 0.59 (− 1.75, 0.58)	**− 2.85 (− 4.81, − 0.89)**	− 1.01 (− 2.01, 0.01)	− 0.55 (− 1.66, 0.59)	SB_CAF

Table 7. League table of the efficacy of different dietary supplements in enhancing the number of throws. Significant values are in bold. *BA* beta-alanine, *CAF* caffeine, *CM* citrulline malate, *CRM* creatine malate, *PLA* placebo, SB sodium bicarbonate, *SB_CAF* sodium bicarbonate + caffeine.

perceived fatigue[102]. Compared to placebo, CHO was associated with a statistically significant enhancement of the accuracy of specific skills (lunge test)[88]. In the context of karate, compared to a placebo, CAF, SB, and CAF_SB were associated with a statistically significant extension of the time to exhaustion of karate athletes in the Karate-specific aerobic test, while causing an increase in blood lactate levels[89]. O3FA_PC had a positive effect on mood state and attention[97]. In the case of kendo, compared to a placebo, Coenzyme Q10 may have an inhibitory effect on changes in toll-like receptor 4 positive / cluster of differentiation 14 positive (TLR-4+/CD14+) cells to a certain extent[87]. At the same time, it is effective in reducing muscle damage indicators (serum creatine kinase activity and serum myoglobin (Mb) concentration) and oxidative stress indicators (lipid peroxidation)[93]. In mixed martial arts, compared to a placebo, VITD_PB improves lactate utilization and has a positive impact on anaerobic performance[90]. VITD_PB significantly reduces inflammation (decreased calprotectin concentrations), alters gut microbiome diversity, and improves exercise tolerance[91]. In the context of sanda, compared to the placebo, VITC_VITE was associated with a statistically significant reduction in serum creatine kinase levels and a statistically significant increase in serum myoglobin levels[92] (Table S2).

Side effects

Among the 67 studies included, 11 studies discussed side effects, and 7 of them found varying degrees of side effects after taking dietary supplements. The observed side effects were mainly linked to supplementation with BA (sensory abnormalities)[41,72], SB (stomach discomfort, hiccups, heartburn, diarrhea, bloating, abdominal discomfort, and urge to defecate)[41,55,65,96], CAF (moderate headache, diarrhea, and abdominal pain)[70], CAF_SB (gastrointestinal bloating)[65], and SC (moderate nausea, burping, severe bloating, urgency to defecate, and diarrhea)[83] (Table S3).

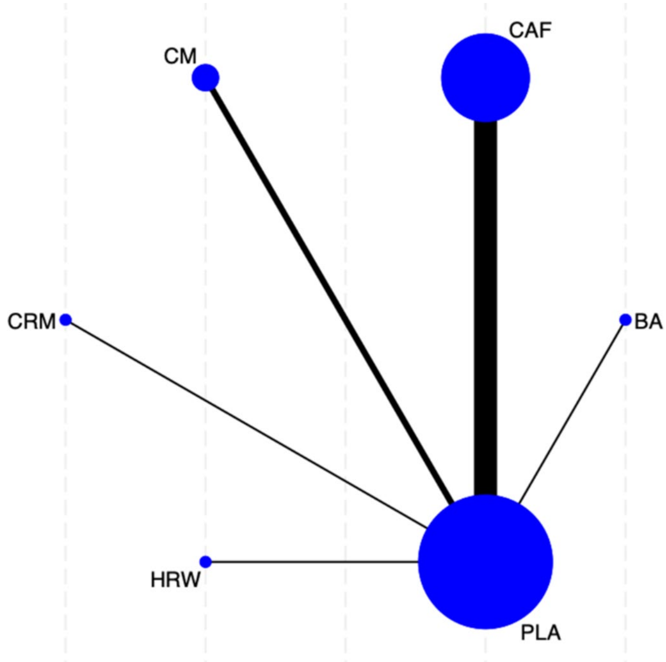

Fig. 10. Network diagram of the efficacy of different dietary supplements in improving special judo fitness test index. *BA* beta-alanine, *CAF* caffeine, *CM* citrulline malate, *CRM* Creatine malate, *HRW* Hydrogen-rich water, *PLA* Placebo.

	BA	CAF	CM	CRM	HRW	PLA
BA	BA	0.65 (− 1.33, 2.5)	0.17 (− 1.83, 2.07)	1.77 (− 0.66, 4.18)	0.63 (− 1.69, 2.71)	0.62 (− 1.36, 2.47)
CAF	− 0.65 (− 2.5, 1.33)	CAF	− 0.47 (− 1.07, 0.14)	1.14 (− 0.32, 2.61)	− 0.03 (− 1.1, 1.04)	− 0.03 (− 0.28, 0.23)
CM	− 0.17 (− 2.07, 1.83)	0.47 (− 0.14, 1.07)	CM	**1.6 (0.08, 3.16)**	0.44 (− 0.76, 1.61)	0.44 (− 0.11, 0.99)
CRM	− 1.77 (− 4.18, 0.66)	− 1.14 (− 2.61, 0.32)	**− 1.6 (− 3.16, − 0.08)**	CRM	− 1.16 (− 2.99, 0.59)	− 1.17 (− 2.62, 0.26)
HRW	− 0.63 (− 2.71, 1.69)	0.03 (− 1.04, 1.1)	− 0.44 (− 1.61, 0.76)	1.16 (− 0.59, 2.99)	HRW	0 (− 1.03, 1.04)
PLA	− 0.62 (− 2.47, 1.36)	0.03 (− 0.23, 0.28)	− 0.44 (− 0.99, 0.11)	1.17 (− 0.26, 2.62)	0 (− 1.04, 1.03)	PLA

Table 8. League table of the efficacy of different dietary supplements in improving special judo fitness test index. Significant values are in bold. *BA* beta-alanine, *CAF* caffeine, *CM* citrulline malate, *CRM* creatine malate, *HRW* hydrogen-rich water, *PLA* placebo.

Discussion

Summary of the main results

The aim of this systematic review and network meta-analysis is to assess the efficacy of various dietary supplements for elite combat sport athletes. The study identified 67 randomized controlled trials, involving 1,026 elite combat sport athletes randomly assigned to 26 different dietary supplements. A network meta-analysis, based on 50 studies, was conducted to evaluate the impact of interventions compared to untreated controls/placebo, as well as pairwise comparisons between interventions. According to the systematic review and network meta-analysis, dietary supplements such as SB_CAF, CAF, BA, and SB were found to be associated with a statistically significant improvement in blood lactate levels in comparison to placebo. Notably, compared to placebo, CAF was associated with a statistically significant enhancement of final heart rate, the number of taekwondo kicks, and the number of throws. Compared to placebo, other dietary supplements that were associated with a statistically significant enhancement of mean and peak power included CR_SB, CR, and SB. However, among the studies included in our network meta-analysis, compared to placebo, no dietary supplements were found to be associated with a statistically significant improvement in the ratings of perceived exercise, special judo fitness test index, and the number of attacks in elite combat athletes.

Comparison with previous studies

Several previous reviews have reported CAF was associated with a statistically significant improvement in blood lactate levels[8,23,25,27], the number of throws[23,25], and final heart rate[23]compared to a placebo. However, compared to placebo, there was not an association with a statistically notable improvement in the rating of perceived exertion[8,23,27] and special judo fitness test index[23], aligning with our findings. Our results also revealed that

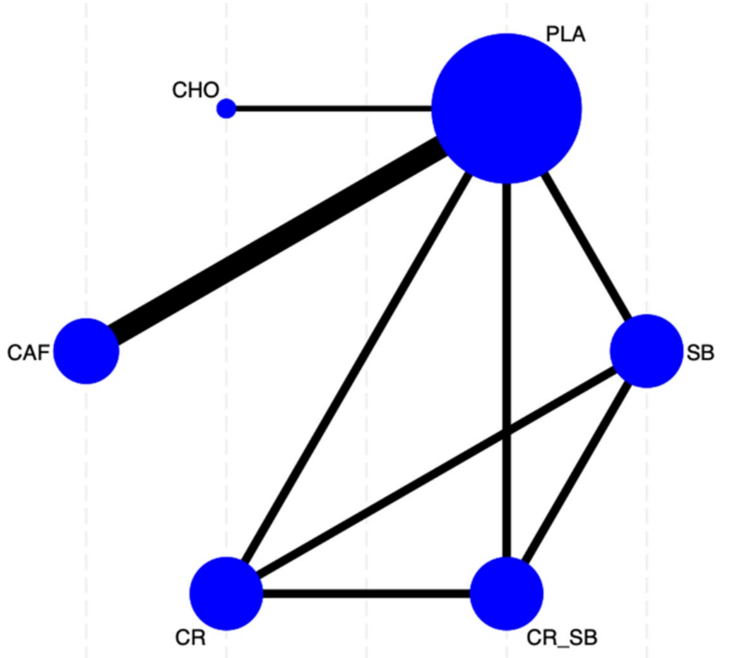

Fig. 11. Network diagram of the efficacy of different dietary supplements in enhancing the number of kicks. *CAF* caffeine, *CHO* carbohydrate, *CR* creatine, *CR_SB* creatine + sodium bicarbonate, *PLA* placebo, *SB* sodium bicarbonate.

	CAF	CHO	CR	CR_SB	PLA	SB
CAF	CAF	− 1.3 (− 4.13, 1.48)	− 1.24 (− 3.71, 1.21)	0.25 (− 2.24, 2.83)	**− 1.44 (− 2.71, − 0.19)**	0.06 (− 2.43, 2.57)
CHO	1.3 (− 1.48, 4.13)	CHO	0.07 (− 3.21, 3.35)	1.55 (− 1.74, 4.95)	− 0.14 (− 2.65, 2.37)	1.36 (− 1.93, 4.7)
CR	1.24 (− 1.21, 3.71)	− 0.07 (− 3.35, 3.21)	CR	1.48 (− 1.5, 4.6)	− 0.21 (− 2.3, 1.92)	1.3 (− 1.7, 4.36)
CR_SB	− 0.25 (− 2.83, 2.24)	− 1.55 (− 4.95, 1.74)	− 1.48 (− 4.6, 1.5)	CR_SB	− 1.69 (− 3.95, 0.46)	− 0.19 (− 3.29, 2.88)
PLA	**1.44 (0.19, 2.71)**	0.14 (− 2.37, 2.65)	0.21 (− 1.92, 2.3)	1.69 (− 0.46, 3.95)	PLA	1.5 (− 0.64, 3.69)
SB	− 0.06 (− 2.57, 2.43)	− 1.36 (− 4.7, 1.93)	− 1.3 (− 4.36, 1.7)	0.19 (− 2.88, 3.29)	− 1.5 (− 3.69, 0.64)	SB

Table 9. League table of the efficacy of different dietary supplements in enhancing the number of kicks. Significant values are in bold. *CAF* caffeine, *CHO* carbohydrate, *CR* creatine, *CR_SB* creatine + sodium bicarbonate, *PLA* placebo, *SB* sodium bicarbonate.

CAF was associated with a statistically significant enhancement of the number of kicks compared to placebo. Interestingly, our study did not observe an association with a statistically significant improvement in grip strength with CAF compared to placebo, in contrast to previous reviews[8,23,27]. One potential reason for this disparity could be the variance in participant characteristics. Our study specifically targets high-level combat athletes, whereas prior research encompassed athletes across a wider spectrum of proficiency[8,23,27]. Elite athletes could have already maximized their neuromuscular performance, potentially resulting in less noticeable advantages from CAF supplementation. Several previous reviews have debated the impact of CAF on the number of attacks. Néstor Vicente-Salar et al. and J Diaz-Lara et al. reported that compared to placebo, CAF was associated with a statistically significant increase in the number of attacks[8,25]. Conversely, Slaheddine Delleli et al. found that compared to placebo, there was no association with a statistically significant improvement, consistent with our results[23]. This discrepancy may be attributable to the different review methods and statistical analyses used. Previous reviews use traditional systematic review and meta-analysis methods[8,25]. In contrast, our analysis uses a network meta-analysis approach, which allows for a more comprehensive assessment of multiple interventions by comparing direct and indirect evidence simultaneously. Because network meta-analysis can capture relationships between interventions that are not assessed in pairwise meta-analyses, different statistical analysis methods used may explain the differences in results. Another potential factor to take into account is the elevated baseline performance levels of elite athletes in our study. In contrast to the non-elite population, elite athletes may exhibit a diminished response to CAF due to their already highly adapted physiological systems, which could explain the absence of significant enhancements in grip strength and the number of attacks. In comparison with placebo, SB was found to be associated with a statistically significant improvement in blood lactate levels but did not show an association with a statistically notable improvements in the rating of perceived exertion and number of throws, aligning with a previous review[29]. However, our study revealed that compared to placebo, SB was associated with

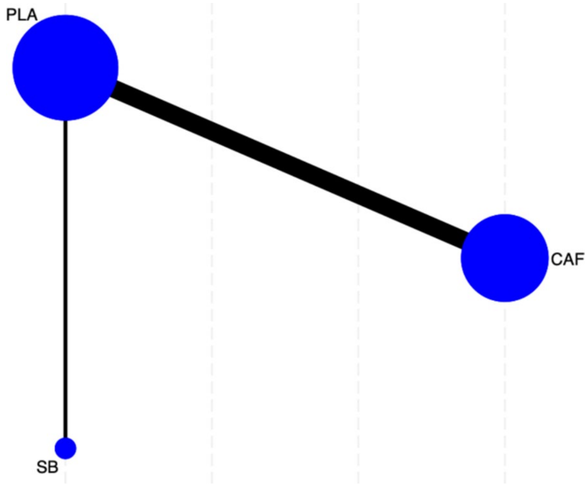

Fig. 12. Network diagram of the efficacy of different dietary supplements in enhancing the number of attacks. *CAF* caffeine, *PLA* placebo, *SB* sodium bicarbonate.

	CAF	PLA	SB
CAF	CAF	− 0.18 (− 0.39, 0.04)	− 0.1 (− 0.69, 0.5)
PLA	0.18 (− 0.04, 0.39)	PLA	0.08 (− 0.48, 0.64)
SB	0.1 (− 0.5, 0.69)	− 0.08 (− 0.64, 0.48)	SB

Table 10. League table of the efficacy of different dietary supplements in enhancing the number of attacks. *CAF* caffeine, *PLA* placebo, SB sodium bicarbonate.

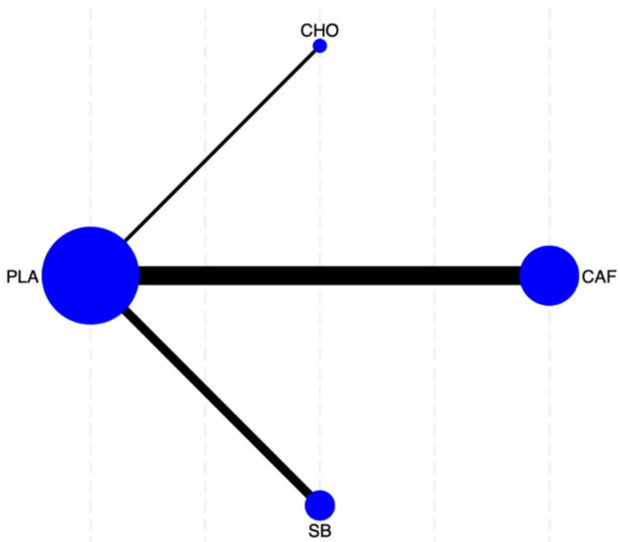

Fig. 13. Network diagram of the efficacy of different dietary supplements in enhancing grip strength. *CAF* caffeine, *CHO* carbohydrate, *PLA* placebo, *SB* sodium bicarbonate.

a statistically significant improvement in both peak power and mean power, contrary to the previous review. The relatively small sample sizes in previous studies may account for the differences in this result, which might have been insufficient to detect potential effects[29]. However, our study, with a relatively larger sample size, provides greater statistical power to more accurately assess the effects of SB supplementation on peak power and average power. It is important to consider the special requirements of combat sports, which largely depend on anaerobic power and anaerobic endurance[7,12]. Sodium bicarbonate is well known for its ability to buffer hydrogen ions during high-intensity exercise, potentially leading to greater power output improvements during short bursts of explosive force[103]. This mechanism can elucidate the significant improvements in peak and average power

	CAF	CHO	PLA	SB
CAF	CAF	**− 0.84 (− 1.62, − 0.07)**	− 0.12 (− 0.29, 0.05)	0.13 (− 0.22, 0.45)
CHO	**0.84 (0.07, 1.62)**	CHO	0.72 (− 0.03, 1.48)	**0.96 (0.18, 1.78)**
PLA	0.12 (− 0.05, 0.29)	− 0.72 (− 1.48, 0.03)	PLA	0.25 (− 0.04, 0.53)
SB	− 0.13 (− 0.45, 0.22)	**− 0.96 (− 1.78, − 0.18)**	− 0.25 (− 0.53, 0.04)	SB

Table 11. League table of the efficacy of different dietary supplements in enhancing grip strength. Significant values are in bold. *CAF* caffeine, *CHO* carbohydrate, *PLA* placebo, SB sodium bicarbonate.

observed in our study. Furthermore, different power testing methods may also contribute to varied results. A previous review indicated that BA alone was associated with a statistically significant improvement in the special judo fitness test index and the number of throws compared to placebo[1], with no association with a statistically significant improvement in the rating of perceived exertion. In our study, compared to placebo, BA was not associated with a statistically significant improvement in the rating of perceived exertion, special judo fitness test index, or the number of throws. Our research is centered on elite combat athletes, who may already possess a high baseline performance level. This could reduce the likelihood of significant further improvements from BA supplementation. Previous studies have encompassed athletes of different competitive levels, thereby making the impact of BA more apparent[1]. Furthermore, the differences in training protocols may influence the impact of BA on these performance indicators. BA has the potential to enhance performance in physical activities that induce an extreme acidotic environment within the muscles[104]. However, when the training protocol does not result in severe muscle acidosis, the enhancement in athletic performance is constrained[105]. Our study found that compared to placebo, SB_CAF was not associated with a statistically significant improvement in blood lactate levels. This finding has addressed a gap in a previous review that suggests the need for more studies on caffeine and sodium bicarbonate combinations to verify clear synergistic effects[8]. Current studies on dietary supplements and athletic performance in combat athletes predominantly focus on wrestling, judo, jujitsu, and taekwondo, with fewer studies on boxing, fencing, karate, kendo, sanda, and mixed martial arts. Current studies focused mostly on CAF and SB, rarely on other dietary, which may be attributable to project characteristics and the distinct effectiveness of various dietary supplements. Hence, a more comprehensive and diverse range of studies is essential to examine the effects of different dietary supplements on performance in various combat sports.

Strengths and limitations of the study

To our knowledge, this is the first comprehensive systematic review with NMA of available effectiveness data on dietary supplements for elite combat athletes. The study has its limitations. First, combat sports encompass a wide array of fighting styles. In our comprehensive review, we have meticulously examined and provided evidence-based support for judo, jujitsu, wrestling, and taekwondo. Despite an extensive analysis of the literature, we faced limitations in conducting a quantitative network meta-analysis due to the scarcity of research on dietary supplements for other combat sports such as boxing, karate, kendo, fencing, kickboxing, and mixed martial arts.

Second, based on the recently established athlete classification framework by Alannah K.A. McKay et al.[32], our systematic review examined the impact of dietary supplements on the athletic performance of trained elite combat athletes. Consequently, this may restrict the number of samples included in eligible studies and may be confined to providing information on dietary supplements currently available (and used) in elite combat sports. Research on high-level combat athletes may be hindered by various factors, resulting in limited data in this field. For example, the substantial variation in training regimens and competition schedules among different combat sports can present difficulties in standardizing study conditions and comparing results across studies. Moreover, challenges in recruiting and retaining elite athletes due to their demanding schedules and intense training commitments pose further complications for research efforts. It is important to acknowledge the influence of these factors on the interpretation of results. Therefore, teams supporting nutritional health and athletic performance should exercise caution in interpreting the available evidence.

Although this systematic review was limited by scope and data constraints, we did not explicitly assess other potential influencing factors, such as gender and weight category. However, we acknowledge that these factors may affect the effectiveness of dietary supplements. Future research would benefit from a more thorough exploration of these variables to gain a better understanding of their impact on outcomes.

Moreover, several limitations of this network meta-analysis should be acknowledged. Given the small number of studies on some supplements, the ranking of these interventions is relative to the included studies (i.e., sensitive to the inclusion of other studies), and the network results should be treated with caution. Additionally, since there's placebo effects that may reduce the magnitude effects of the supplements as compared to a blank control, supplements that were investigated within placebo-controlled studies may result in lower impact than those with blank control reference group. Furthermore, it was more applicable to use a multilevel network meta-regression model to avoid potential aggregation bias. Future research should consider utilizing this method to provide a more robust analysis, as suggested by Phillippo et al.[106].

Furthermore, there is a concern about supplement contamination leading to unintentional violations of anti-doping rules. Contamination is quite common and can have serious consequences for athletes. Therefore, considering this risk, recommending the use of specific supplements must take into account the possibility of contamination and its implications for anti-doping compliance.

Conclusions

We conducted a thorough systematic review and network meta-analysis of randomized controlled trials to evaluate the efficacy of various dietary supplements. Based on our comprehensive examination of the current evidence, elite combat athletes can benefit from a variety of dietary supplements that are both safe and effective. These supplements have the potential to enhance evidence-based practices in food and nutrition for this specific population. This analysis offers valuable insights for decision-making. Furthermore, it is imperative to conduct further research in combat sports such as boxing, karate, kendo, fencing, sanda, and mixed martial arts. Additionally, there is a gap in understanding the impact of dietary supplements on elite female combat athletes. More studies are required to gain a deeper insight into the effectiveness of these supplements for athletes trained in different combat disciplines.

Data availability

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

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Author contributions

All authors contributed to the study conception and design. Writing - original draft preparation: HL; Writing - review and editing: HL, XZ and CX; Conceptualization: HL and XZ; Methodology: HL; Formal analysis and investigation: XZ; Resources: CX; Supervision: NAN and TFTK, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethics statement

This study is a systematic review and does not involve ethics approval.

Additional information

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