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Effects of nutrition education programmes designed to improve dietary intake and nutrition knowledge in female athletes: a systematic review

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Abstract

Proper nutrition enhances athletes' performance and recovery during sports activities. This review aims to investigate the effects of nutrition education interventions on dietary intake, nutrition knowledge, and body composition of female athletes. From a comprehensive search, we identified twenty single-arm and eight double-arm studies that met the inclusion criteria. The interventions in these studies ranged from personalised consultations to group workshops. The mode of delivery was mainly face-to-face. Most of these interventions consisted of group sessions with variable duration and frequency. From the studies finally included, nutrition education intervention significantly increased the nutrition knowledge of female athletes in 76% and improved their dietary intake in 67%. However, only 44% of the studies that measured changes in body composition reported significant changes. Moreover, only a minority of studies (14%) maintained follow-up assessments to measure the lasting impact of the interventions. Overall, 60% of interventions were delivered by professional nutritionists or dietitians, ensuring high-quality education. There is a need for standardised methodologies and more robust study designs to better assess the effectiveness of nutrition education interventions. Knowing athletes' preferences when planning education may improve engagement and intervention efficacy. Also, longer-term follow-up of athletes would allow for a more accurate evaluation of the consolidation of acquired knowledge. Including coaches in nutrition education interventions would probably amplify the impact on athletes' dietary behaviours. Nutrition education can positively influence the knowledge and eating habits of female athletes, but its effect on body composition represents an area where much remains to be explored.

Introduction

According to scientific evidence, appropriate nutrition enhances athletic performance and supports recovery during sports activities[(1)]. Therefore, it is crucial for an athlete's diet to be optimal in both quality and quantity of food to replenish energy stores and obtain the necessary nutrients for the proper functioning and recovery of bodily systems. This helps prevent fatigue, injuries and ill health[(2)].

In addition to adequate nutrition, body composition is a critical determinant of athletic performance[(3)]. A more favourable body composition, characterised by higher muscle mass and appropriate body fat levels, has been associated with improvements in strength, endurance and overall physical performance[(4)]. Maintaining optimal body composition is also essential for injury prevention, longevity in sports and overall health and wellbeing[(5)].

Multiple factors influence an athlete's dietary behaviour, including physiological, psychological, social, economic and organoleptic aspects, as well as convenience, beliefs and nutrition knowledge[(6)]. It has been reported that the level of nutrition knowledge attained by an athlete positively affects their dietary behaviour[(7–12)]. Key areas of nutrition-related knowledge for athletes may include energy requirements, body composition, macronutrient needs, vitamins and minerals, hydration, training diet, supplements and ergogenic aids[(13)].

Female athletes experience growth and development differently compared with male athletes, resulting in substantial differences in body size and composition, as well as a unique hormonal environment[(14)]. These distinctive physiological characteristics cause females to face specific nutrition and health challenges related to physiological changes and nutrition stress induced by strenuous exercise, factors that can significantly impact overall wellbeing.

Research on female athletes frequently reports restrictions in energy intake, leading to inadequate coverage of energy and nutrition needs, which negatively impacts athletic performance. Some female athletes may deliberately restrict their calorie intake for performance

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or aesthetic reasons, while others may have insufficient energy intake owing to other factors such as increased training load or lack of education on proper nutrition according to their sports demands[15]. If this energy deficit persists, a condition known as low energy availability (LEA) develops. LEA occurs when caloric intake does not meet the energy expenditure of exercise, leaving insufficient energy for essential bodily functions, which affects health and performance[16]. In the long term, it can disrupt the physiological and psychological functioning of athletes, compromising metabolism, reproductive function, bone and muscle health, the immune system and cardiovascular health. This state, known as relative energy deficiency in sport (RED-S), increases the risk of injuries and may reduce athletic performance[16].

Studies report that nutrition knowledge among this population is insufficient[7,17,18]. The lack of well-structured and effective nutrition education interventions, combined with the widespread dissemination of misinformation in sports environments and the contradictory dietary advice from friends, family, coaches and online sources[19], highlight the need to incorporate nutrition education into sports programmes, as this is one of the few modifiable determinants of dietary behaviours[20].

Nutritional education is a structured process that provides knowledge and skills to make informed decisions about diet and physical activity. Its goal is to promote healthy habits by encouraging appropriate food choices at both individual and community levels[21]. Interventions in this field aim to enhance the target population's nutritional knowledge to foster healthier eating habits[22]. Nutrition education can be implemented in various modalities, including group education sessions[23], the use of technological platforms[24], graphic materials[25] and interactive workshops that incorporate practical skills such as cooking, daily menu planning or grocery shopping[26,27]. In contrast, individual nutrition consultations[10] are dynamic, two-way interactions where the client actively participates in defining and implementing key behavioural changes. These consultations build upon the client's existing nutritional knowledge and typically take place within an ongoing professional relationship, where the nutrition advisor works privately with the client across multiple individualised sessions[28]. Given that some studies report that coaches and other sports specialists have inadequate nutrition knowledge[29], which could impact the knowledge acquired by the athletes themselves, planned nutrition education could be directed at both athletes and coaches.

Although general research on athletes has historically been more extensive in men[24,30–33], interest in nutritional education interventions for female athletes has been increasing. This indicates a significant effort to study this population in the context of nutrition education. However, it remains essential to expand research to ensure comprehensive coverage across different sports, age groups and competitive levels. Female athletes face particular challenges, including specific nutritional needs, a higher risk of low energy availability and RED-S. In addition, some studies suggest that there are differences in preferred learning styles according to gender[34] and also in emotional aspects linked to engagement in learning[35]. Accordingly, female athletes may respond differently to the same nutrition education intervention than male athletes, and aggregating data from both sexes in such interventions, or analysing the data without considering gender, may result in a gender bias. Despite these factors, although reviews on nutritional education interventions in athletes have been conducted[8,36–38], none have focused exclusively on female athletes, highlighting the need to address this gap in literature.

Table 1. PICO strategy used in the systematic review

P	Population	Female athletes from 10 to 30 years old
I	Intervention	Nutrition educational intervention
C	Control	Control group or with the individual himself as a control
O	Outcome	Changes in dietary intake, nutrition knowledge and/or body composition

Consequently, this systematic review was conducted exclusively with female athletes to analyse and evaluate the available evidence on the effect of nutrition interventions on knowledge and dietary intake. In addition, it aims to determine whether these interventions influenced the athletes' body composition, given its critical role in performance, injury prevention and overall health. This information will facilitate the design and implementation of effective interventions to enhance nutrition knowledge, dietary intake and/or body composition among female athletes.

Materials and methods

This systematic review was conducted following the recommendations and criteria outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)[39] statement guidelines and was registered on Prospero (CRD42023406986).

Search strategy

To identify potential studies, a search was conducted in the electronic databases PubMed/Medline, Scielo, Cinahl, Web of Science and Scopus. The search strategy was structured on the basis of the Population, Intervention, Control, and Outcome (PICO) framework (Table 1), incorporating keywords and controlled vocabulary, athlete*, sport*, team sport*, 'nutrition feedback', 'educational intervention', 'nutrition intervention', 'nutrition intervention', 'nutrition education', 'nutrition program*', 'health education', 'dietary intervention', 'dietary program*, 'energy intake', 'energy balance', 'feeding behavior', 'dietary intake', 'dietary behav*', 'dietary pattern*', 'dietary habit*', 'dietary assessment', 'eating behav*', 'eating patterns', 'eating habits', 'nutrition intake', 'nutrition habits', 'nutrition patterns', 'nutrition status', 'food choice', 'food habit*', 'nutrition knowledge', 'health knowledge', 'food knowledge', 'diet knowledge', 'body composition', 'weight management'.

The systematic literature search to identify studies was conducted by one researcher (M. V.) in March 2023 and repeated in May 2024 to identify newly published articles. The search strategy used was the same for all databases (Supplementary Table S1), applying filters for language (English, Spanish, Italian, French, Portuguese, and Catalan), publication year (since 1990) and studies involving human subjects. In addition, a manual search using the snowball strategy was conducted to identify any additional articles not initially captured in the search.

Inclusion and exclusion criteria

Studies meeting the following criteria were included in our review: (1) population: female athletes aged between 10 and 30 years old, of different ethnicities, nationalities, sports and competitive levels; (2) type of intervention: administration of a nutrition education programme without restrictions regarding duration or modality;

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(3) outcomes: assessment of dietary intake, nutrition knowledge and/or nutrition status, before and after the intervention; (4) control: studies could include a control group with or without intervention, or no control group; (5) study designs: randomised controlled trials (RCTs), quasi-experimental studies and community intervention trials; (6) type of publication: peer-reviewed articles and doctoral dissertations.

The exclusion criteria were: (1) athletes diagnosed with eating disorders or any chronic pathology that requires special dietary planning (for example, diabetes); (2) type of intervention: studies administering dietary supplements or psychological interventions concurrently with nutrition education, or those solely providing dietary guidelines without nutrition education; (3) study designs: case studies and nutrition intervention studies assessing only the final outcome; (4) type of publication: abstracts, conference posters, narrative reviews, systematic reviews, meta-analyses and letters to the editor; (5) studies that do not report results disaggregated by sex.

Selection of studies

After performing the predetermined search strategy across the above-mentioned databases, the first author (M. V.) exported all results to the Rayyan reference management system (RAYYAN, Cambridge, MA, USA) and proceeded to remove duplicate references. Then, manuscript titles and abstracts were examined independently by two authors (M. V. and A. F.). Full-text versions of studies that met the inclusion criteria were then screened. Discrepancies regarding the inclusion of studies between authors were resolved by consensus with a third author (R. F.). When an article contained insufficient details, we tried to obtain the missing information by contacting the authors via email (M. V.). If translation of the articles was necessary, the DeepL application was employed (DeepL, Köln, Germany), with the translated version subsequently verified by the first author (M. V.).

Data extraction

Data extraction was independently conducted by two authors (M. V. and A. F.) using an Excel data extraction form. This form included fields for demographic characteristics (authors' names, publication year, country where the study was conducted, sport, sample size, mean age and standard deviation, and/or age range), intervention details (type of intervention, delivery mode, duration and frequency, nutrition education curriculum and facilitator), outcomes (tools/questionnaires/parameters/tests used for each analysed variable) and main findings (increased/decreased/unchanged effects on dietary intake, nutrition knowledge and/or body composition). The studies were grouped according to their design: one Excel data extraction form was used for single-arm studies (intervention group only) and another for double-arm studies (intervention and control groups).

Given that most of the included studies assessed nutrition knowledge, the total scores of each administered questionnaire and pre- and post-intervention scores were extracted and tabulated in a spreadsheet.

Quality assessment

Study quality was independently assessed in duplicate by two authors (M.V. and A.F.), with a third author (R.F.) consulted to resolve any discrepancies. A modified version of the Downs and Black checklist[40] was used (Supplementary Table S2). Out of the original twenty-seven items, twenty-four were retained, while items 8, 13 and 17 were eliminated[8]. In addition, two items from the Academy of Nutrition and Dietetics (AND) quality criteria checklist were incorporated[41]. Specifically, these were item 9, 'Are conclusions supported by results with biases and limitations taken into consideration?' and item 10, 'Is bias due to study funding or sponsorship unlikely?'[8].

In the checklist, each question is answered with a 'yes' if the criteria are satisfied or a 'no' if they are not. A score of 1 point was assigned for all items answered 'yes' (with 0 points given for 'no'), except for items 5 and 18, which could score a maximum of 2 points.

For studies employing single-arm designs, items 14, 15, 21, 22, 23 and 24 were excluded. Thus, the maximum score for studies utilising this design was 22 points, with the following scoring criteria applied: ≤ 11 points for poor quality, 12–15 points for fair quality, 16–19 points for good quality and 20–22 points for excellent quality. For studies using double-arm designs, the maximum score was 28 points. The scoring criteria adopted were as follows: ≤ 14 points for poor quality, 15–19 points for fair quality, 20–25 points for good quality and 26–28 points for excellent quality[8].

Data analysis

Owing to the heterogeneity of the instruments used to assess nutrition knowledge and dietary intake, it was not appropriate to conduct a meta-analysis.

To facilitate inter-study comparisons, original raw scores from nutrition knowledge questionnaires were converted into percentages when necessary. Data were represented in a tree diagram for convenience of presentation. Although the collected data did not meet criteria for meta-analysis as per Cochrane guidelines, effect sizes were calculated to quantify the magnitude of intervention impacts[42]. Effect sizes (ES) with their 95% confidence intervals were calculated using Hedges' *g* for double- and single-arm studies that had reported means and standard deviations (SD). Effect sizes were interpreted using Cohen's cut-off points (very small effect $<0{\cdot}2$; $0{\cdot}2\leq$ small effect $<0{\cdot}5$; $0{\cdot}5\leq$ moderate effect $<0{\cdot}8$; large effect $\geq 0{\cdot}8$). All the statistical calculations were performed using the STATA software version 18 (StataCorp LLC, College Station, TX, USA).

Results

Study selection

Out of the 2788 articles identified from the combined searches, 1813 remained after removing duplicates. Screening on the basis of title and abstract narrowed down the selection to fifty articles for full-text review. Following evaluation against the inclusion and exclusion criteria, twenty-eight articles were ultimately selected for the systematic review (Fig. 1)[9–12,23,25–27,43–60].

Study characteristics

Of the twenty-eight included studies, 71% ($n = 20$) employed a single-arm design, while 29% ($n = 8$) utilised a double-arm design. The characteristics of single-arm and doubled-arm studies are shown in Tables 2 and 3, respectively. It is noteworthy that although Laramée *et al.*[46] implemented a double-arm design, both groups received some form of intervention (intervention group: nutrition education plus behaviour change; control group:

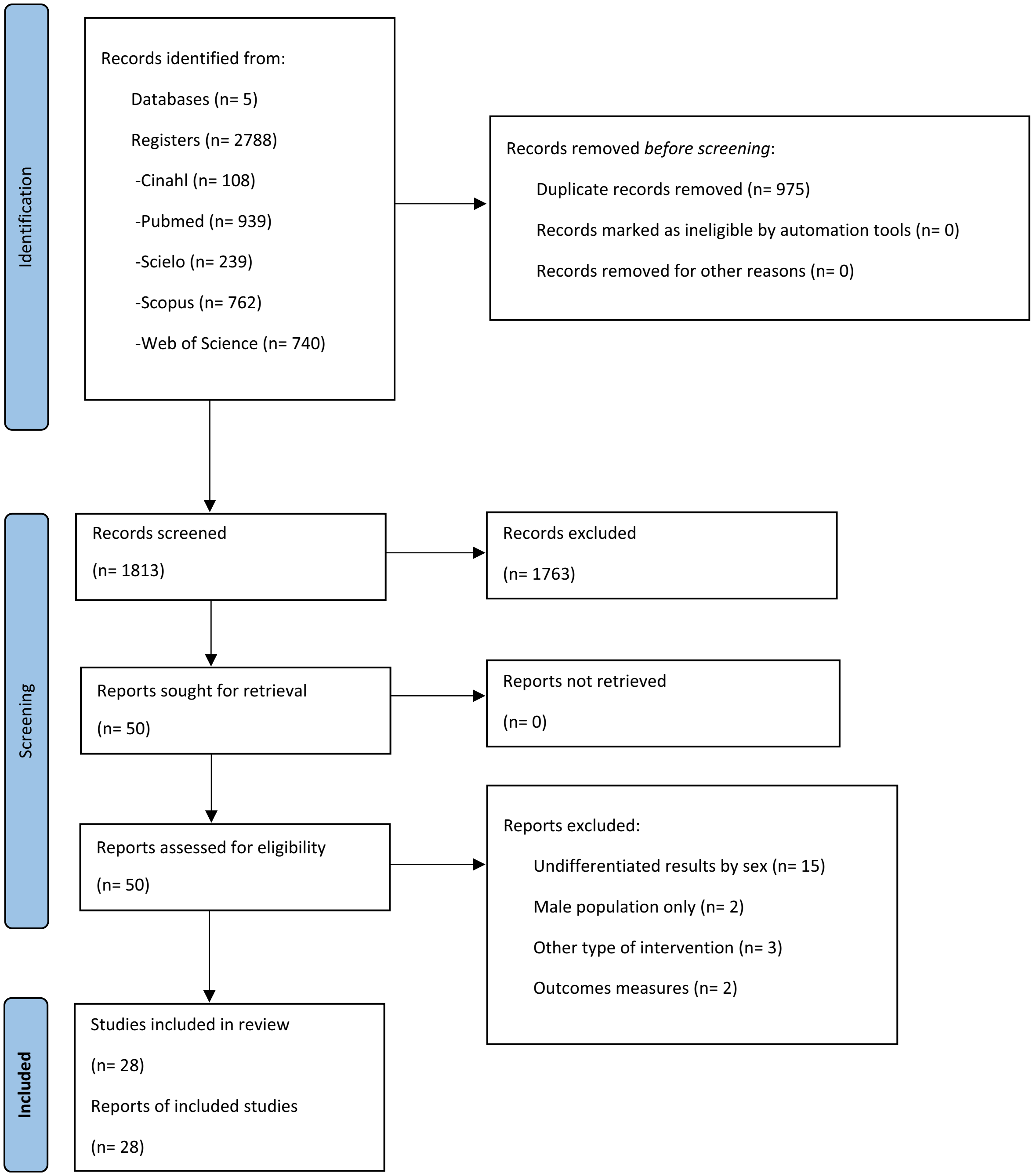

Fig. 1. PRISMA flow diagram showing the study inclusion process.

nutrition education only). Therefore, this study was analysed as a single-arm design, with only the control group data included in the data analysis, because psychological interventions were beyond the scope of this review. There is some possibility that the studies by Valliant *et al.*[10] and Wenzel *et al.*[43] were actually conducted on the same sample and are in fact the same study. Given the impossibility of obtaining this information from the authors, we have chosen to consider them as two separate studies.

Among the studies included in this review, sixteen focused exclusively on female athletes, while twelve covered both sexes. The total sample consisted of 993 female athletes, with individual study samples ranging from 4 to 138 participants. The weighted mean age of the athletes was 16·9 (SD = 1·7) years (range: 11–30 years). Four studies[43,45,50,61] were omitted from age calculations owing to inadequate reporting of mean age and/or standard deviation.

The studies were conducted across various regions, including the USA ($n = 10$), Poland ($n = 3$), Brazil ($n = 2$), Spain ($n = 2$), Algeria ($n = 1$), Australia ($n = 1$), Canada ($n = 1$), Cyprus ($n = 1$), Finland ($n = 1$), Greece ($n = 1$), Ireland ($n = 1$), Italy ($n = 1$), Malaysia ($n = 1$), Turkey ($n = 1$) and UK ($n = 1$). Most of the studies involved female athletes that engaged in only one type of sport ($n = 15$), while the remaining studies included samples with more than one type of sport ($n = 13$). The representation of twenty-one different sports was observed, with athletics or endurance athletes ($n = 14$) and volleyball ($n = 9$) emerging as the most predominant among them. A one-arm study included

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Table 2. Study demographics, intervention details, outcomes and key findings for single-arm studies

	Study demographics			Intervention					Outcomes	
Reference	Sport	Sample size (n)	Age in years: Mean (SD) and/ or rank	Description	Mode of delivery	Duration and frequency	Nutrition curriculum	Facilitator	Outcomes	Key findings
Aguilo et al., 2021 (Spain)[26]	Artistic gymnasts	24	14.1 (2.3)	Nutrition education sessions + dietary counselling session (individual feedback about food intake), workshops (cooking, planning a menu and preparation of snacks) and flyers (hydration)	F2F (in person †) + material delivery	For 8 months: 3 × 45–90 min, once per month (nutrition education sessions) 1 × 15–30 min (dietary counselling session) 3 × 45–90 min, once per month (workshops)	Healthy eating, myths in food and hydration	Nutritionist †	Dietary intake: 3 × 24h-recall FFQ (Schröder et al., 2001) Diversity of the diet: DDS (Fransen et al., 2008) Adherence to the Mediterranean diet (Bach-Faig et al., 2011) NKQ: Mod (Parmenter et al., 1999) Body composition: weight, height, BMI, body fat mass and fat-free mass	Significant increase in energy intake (p = 0.015), carbohydrates (p = 0.004) and vitamin E (p < 0.001). Increase in the % of fat-free mass (p = 0.003) and decrease in the % of fat mass (p = 0.003). There were no significant changes in nutrition knowledge, dietary habits, and adherence to the mediterranean diet.
Anderson, 2010 (USA)[47]	Volleyball	8	19.3 (0.5)	Dietary counselling session (individual feedback about food intake and recommendations) and flyers	F2F (NR) + material delivery	No feedback during the first season (baseline). Feedback 3 times in the second full season (beginning, peak and after). There is no information on duration and frequency	Importance of adequate energy, carbohydrates and protein consumption for the heavy demands of training, a list of carbohydrate foods that could be included in their diets while both dining at home and traveling, sources of protein, advice on how to reduce fat intake, importance of fibre for health and a variety of food sources and importance of vitamin C and calcium consumption	NR	Dietary intake: 3-day food record Body composition: weight, height, BMI and body fat mass	Protein intake was significantly greater in Feedback-Beginning compared to Baseline-Beginning ($p \leq 0.05$). The only vitamin with significantly different consumption was vitamin C, with intakes of Feedback-Beginning vs. Baseline-Beginning ($p \leq 0.05$). A significantly greater amount of calcium was consumed at Feedback-Beginning compared to Baseline-Beginning. Body composition was unaffected by feedback at beginning, peak, and after.

Table 2. (*Continued*)

Collison et al., 1996 (USA)[48]	Volleyball, field hockey and tennis	28	19.4 (1.2)	Workshop ("Nutrition: fac or fiction?" and "What´s in a label?")	F2F (in person ‡)	2 sessions, once a week (no additional information)	Energy needs and sources, fat and cholesterol content in foods, synthetic vs. natural foods, fluids for athletes, vitamins and minerals, diet and weight control, and osteoporosis and bone health.	NR	Dietary intake: 3-day food record NKQ + NAQ: Mod (Werblow et al., 1978)	Significant increase in nutrition knowledge (p <0.0005) and a more positive attitude towards nutrition ($p < 0.0005$). No changes in dietary intake were observed.
Daniel, et al., 2016 (Brazil)[49]	Volleyball	10	17.2 (0.9)	Nutrition education sessions, games, discussion and workshop (culinary)	F2F (in person)	6 sessions, twice a week (no additional information)	Healthy diet, nutrition and sports performance, pressure for results, anxiety and eating, antioxidants in fruits and vegetables, energy equivalence, body image and healthy food choices.	Nutritionist	NKQ: No mod (Jürgensen et al., 2015)	Significant increase in nutrition knowledge ($p = 0.03$).
Kunkel et al., 2001 (USA)[50]	Athletes	32	NR	Individual or group meetings and flyers (Food pyramid)	F2F (in person) + material delivery	Once a week (no additional information)	Basic nutrition and encouraged positive dietary behavioural habits by discussing the Food Guide Pyramid, serving sizes, healthy food choices by selecting foods from a variety of sources, in-season and out-of-season diets, pre competition meals, weight management, snacks, and guidelines for eating out.	Dietetic student	NKQ + NAQ: No mod (Werblow et al., 1978)	Significant increase in nutrition knowledge ($p < 0.05$). No significant changes were observed in nutrition attitude.
Lagowska et al., 2014 (Poland)[51]	Ballet dancers and athletes (rowers, synchronized swimmers and triathlonists)	Ballet dancers: 21 Athletes: 31	Ballet dancer: 17.1 (0.9) Athletes: 18.1 (2.6)	Dietary counselling session (nutrition feedback regarding dietary intake, planning of an individual diet and dietary education)	F2F (NR)	For 9 months (no additional information)	Consequences of nutrition deficiencies, special foods for athletes, sports drinks, supplements, shopping tips, low-fat and low-calorie food, food preparation, dining out, iron, calcium and vitamins in foods.	Registered Dietitian	Dietary intake: 7 consecutive days of dietary records Body composition: weight, height, BMI, body fat mass and fat-free mass	Significant increase in energy ($p < 0.001$), protein ($p < 0.001$) and carbohydrate ($p < 0.001$) intake in the total sample. In addition, the ballet dancers registered a significant increase in fat intake (p <0.001). No significant changes in body composition.

(*Continued*)

Table 2. (*Continued*)

	Study demographics			Intervention					Outcomes	
Reference	Sport	Sample size (n)	Age in years: Mean (SD) and/ or rank	Description	Mode of delivery	Duration and frequency	Nutrition curriculum	Facilitator	Outcomes	Key findings
Lagowska et al., 2014 (Poland)[52]	Rowers, synchronized swimmers and triathlonists	31	18.1 (2.6)	Dietary counselling session (nutrition feedback regarding dietary intake, planning of an individual diet and dietary education)	F2F (NR)	For 3 months (no additional information)	Consequences of nutrition deficiencies, special foods for athletes, sports drinks, supplements, shopping tips, low-fat and low-calorie food, food preparation, dining out, iron, calcium and vitamins in foods.	Registered Dietitian	Dietary intake: 7 consecutive days of dietary records Body composition: weight, height, BMI, body fat mass and fat-free mass	Significant increase in energy ($p = 0.04$), protein ($p = 0.004$), carbohydrate ($p < 0.001$), calcium ($p = 0.02$), magnesium ($p = 0.003$), vitamin A ($p < 0.001$), vitamin D ($p = 0.04$), foliate ($p = 0.01$) and vitamin C ($p = 0.002$) intake. No significant changes in body composition.
Laramée et al., 2017 (Canada)[46]	Gymnasts and cheerleaders	33	13.1 (1.2) and 12–17 years	Nutrition education sessions	F2F (NR)	For 12 weeks: 3 × 60 min, 3 per week (nutrition education sessions)	Energy needs in athletes, carbohydrates, proteins, lipids, strategies to select nutritious food while eating out, identify the right foods before, during, and after training, and the importance of hydration.	Registered dietitian	NKQ : No mod (Morissette et al., 2015)	Significant increase in nutrition knowledge score from baseline after the 3-week intervention ($p < 0.01$).
Lydon et al., 2023 (Ireland)[53]	Football, hurling and handball	89	15.5 (2.3)	Workshop and guide (nutrition guidelines for optimal sports performance and daily menu plans along with healthy easy-to-prepare recipes)	F2F (in person) + material delivery	1 × 3 hour (workshop)	Nutrition guidelines for optimal sports performance and daily menu plans along with healthy easy to prepare recipes.	Teachers	NKQ: AD	Significant increase in nutrition knowledge ($p < 0.05$).
Martinelli et al., 2013 (UK)[54]	Basketball, rugby and water polo	4	21.6 (2.4) (female and male) and 18–23 years	Nutrition education sessions (individual) and workshop	F2F (in person)	For 5 months: 6 sessions, once per month (no additional information)	Introduction to sport nutrition; focus on fuelling, interpreting diet analysis, optimising hydration, recovery nutrition, protein and supplements.	Nutritionists	Dietary intake: 7 consecutive days of dietary records NKQ: AD Anthropometric measure-ments: weight, height and BMI	Significant increase in nutrition knowledge ($p = 0.0212$). There was no significant impact on dietary intake or anthropometric measurements

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Table 2. (*Continued*)

Nowacka et al., 2016 (Poland)[61]	Canoeists	8	16–26 years	Dietary counselling session and workshop (individual and group)	F2F (NR)	For 2 years (no additional information)	Nutrition guidelines and nutrition mistakes.	Nutritionist	Dietary intake: 3-day food record Body composition: weight, height, BMI, body fat mass and fat-free mass	No significant changes in dietary intake and body composition were observed after the intervention.
Philippou et al., 2017 (Cyprus)[27]	Swimmers	11	15.2 (1.5) and 13–19 years	Nutrition education sessions, workshop (educational guided supermarket tour; instructed on reading food labels) and flyers	F2F (in person) + material delivery	For 12 weeks: Half day (no additional information)	Mediterranean diet, sports nutrition for adolescent swimmers and use and misuse of dietary supplements in sports.	Dietitians	Adherence to the Mediterranean diet: KIDMED Index NKQ: AD	Significant change in the KIDMED Index between baseline and post-intervention with as hift toward a better adherence to the MD (p = 0.005). The proportion of swimmers classified as having good adherence to the DM post-intervention increased from 0% to 36%. No significant changes in nutrition knowledge.
Sahnoune et al., 2020 (Algeria)[55]	Athletics, handball, basketball, swimming and judo	39	15 (1.0) and 11–17 years	Dietary counselling session (individual), workshop and material (cookbook with healthy food recipes, and MD pyramid picture)	F2F (in person) + material delivery	For 6 months (no additional information)	MD pyramid principles, importance of fruits, and vegetables consumption, grain cereals, and increased fish consumption and nutrition recommendations for athlete meal.	Nutritionist	Dietary intake: 24-hour recall Adherence to the Mediterr-anean diet: KIDMED Index Anthropometric measure-ments: weight, height and BMI	After 6 months of evaluation, a significant increase in the intake of total carbohydrates, complex carbohydrates, fibre, magnesium, folic acid and vitamin C is observed. Significantly increased the KIDMED Index score (p = 0.000) and the proportion classified as having good adherence to the DM post-intervention increased from 10% to 46%. No significant changes in anthropometric measurements.
Sánchez-Díaz et al., 2022 (Spain)[58]	Basketball	10	13.1 (0.4) (female and male)	Nutrition education sessions (slide show presentation, discussion and games)	F2F (in person + online)	For 5 months: 5 × 1 h, once per month (nutrition education sessions)	Food groups (e.g., foods and nutrients), varied and balanced diet (e.g., recommended and usual portion), food typologies (e.g., fresh and processed) and nutrition labeling.	Nutritionists and dietitians	NKQ + NHQ: Mod (Turconi et al., 2003)	No significant changes were detected in eating habits and nutrition knowledge.

(*Continued*)

Table 2. (*Continued*)

	Study demographics			Intervention					Outcomes	
Reference	Sport	Sample size (n)	Age in years: Mean (SD) and/ or rank	Description	Mode of delivery	Duration and frequency	Nutrition curriculum	Facilitator	Outcomes	Key findings
Tan et al., 2022 (Australia)[56]	Triathletes	9	18.9 (1.6) (female and male)	Nutrition education sessions (visual aids, online chat, short quizzes and practical activities), dietary counselling session (individual) and material	F2F (online) + material delivery	For 8 weeks: 5, once per week (nutrition education sessions delivered remotely) 2 × 30 minutes, once per week (dietary counselling session)	Training nutrition, energy availability, hydration, macronutrient and micronutrient requirements, supplements, food safety, and travel nutrition.	Accredited Sports Dietitian	Dietary intake: 4-day food record (mobile application Easy Diet Diary) NKQ: Mod (Zinn et al., 2005)	No significant changes were detected in dietary intake and nutrition knowledge.
Terenzio et al., 2021 (Italy)[57]	Athletics (jumping and running)	46	16.1 (2.3) and 13–25 years	Dietary counselling session (specific nutrition guidelines for athletes)	F2F (NR)	For 15 months: 2 sessions (no additional information)	Importance of having five meals per day, the role of daily consumption of fruit and vegetables, the suggested amount of daily water intake, the importance of reducing the consumption of sweetened beverages and sugary snacks, how to organize daily food choices, snacks and when the use of supplements is necessary.	Nutritionists	NHQ: AD Anthropometric measure-ments: weight, height, BMI and waist circumference	Significant increase in legumes ($p < 0.001$) and fish intake (0 = 0.012). After the intervention, significant slight increases were observed in BMI, but no significant changes were observed in BMI category.
Valliant et al., 2012 (USA)[10]	Volleyball	11	19.5 (1.0) and 19–22 years	Dietary counselling session (individual)	F2F (NR)	For 4 months: 4 meetings, once per month (no additional information)	The types and amounts of foods specific to their individual dietary needs and activity level.	Registered Dietitian	Dietary intake: 3-day food record NKQ: No mod (Reilly et al., 2007) Body composition: weight, height, BMI, and body fat mass	Significant increase in total energy ($p = 0.002$), carbohydrate ($p = 0.01$) and protein intake ($p = 0.01$). Significant increase in nutrition knowledge ($p = 0.001$). Increase in the % of fat-free mass ($p \leq 0.05$) and decrease in the % of fat mass ($p \leq 0.05$).

Table 2. (*Continued*)

Wenzel et al., 2012 (USA)[43]	Volleyball	11	19.8 and 19–21 years	Dietary counselling session (individual)	F2F (in person)	For 4 months: 4 meetings, once per month (no additional information)	Practical ways to consume regular meals and snacks, basic meal planning and food preparation, general nutrition information, and food purchasing.	Registered dietitian	Dietary intake: 3-day food record Body composition: weight, height, BMI, and body fat mass	Significant increase in total energy ($p < 0.05$), carbohydrate ($p < 0.01$) and protein intake ($p < 0.05$). Body fat percent significantly decreased ($p < 0.01$).
Yannakoulia et al., 2002 (Greece)[62]	Dancers	32	20.5 (1.6) and 19–25 years	Nutrition education session (lectures, discussions and workshops)	F2F (in person)	For 12 weeks: 12 × 2 h, once per week	Nutrition education, primary prevention of eating disorders, and applied nutrition for dancers.	NR	Dietary intake: 3-day food record NKQ: AD Body composition: weight, height, BMI, and body fat mass	No significant changes in nutrient intake were reported. Alcohol intake decreased significantly, both as absolute intake ($p = 0.009$) and as a percentage of total energy intake ($p = 0.004$). Significant increase in nutrition knowledge ($p < 0.0001$). No significant changes in body composition.
Zaman et al., 2021 (Malaysia)[11]	Basketball, aerobic dancers, frisbee, volleyball and track & field	10	24.6 (4.6) and 19–30 years	Nutrition education session (lectures and discussions)	F2F (NR)	One day (from 8:00 a.m. to 5:30 p.m.)	Food and healthy nutrition, macronutrients, micronutrient, fluid and hydration, nutrition before, during and after training or competition, dietary supplement and energy balance and weight management.	Sports nutrition lecturers	Dietary intake: 3-day food record KAP-Sports nutrition question-naire: No mod (Hornstrom et al., 2011)	Significant increase in total energy ($p = 0.001$), carbohydrate ($p = 0.001$), protein ($p = 0.009$) and fat intake ($p = 0.001$). Significant increase in knowledge ($p = 0.007$), attitude ($p = 0.035$), and practice ($p = 0.042$) scores in sports nutrition.

SD, standard deviation; F2F, face to face; NR, not reported; FFQ, food frequency questionnaire; DDS, diet diversity score; NKQ, nutrition knowledge questions; NAQ, nutrition attitudes questions; NHQ, nutrition habits questions; KAP, knowledge, attitude, and practice; AD, author designed instrument; Mod, modified pre-existing instrument; No mod, used original instrument without modification.
†Additional information provided by author
‡Deduced by the researcher

Table 3. Study demographics, intervention details, outcomes and key findings for double-arm studies

	Study demographics			Intervention					Outcomes	
Reference	Sport	Sample size (n)	Age in years: Mean (SD) and/ or rank	Description	Mode of delivery	Duration and frequency	Nutrition curriculum	Facilitator	Outcomes	Key findings
Abood et al., 2000 (USA)[44]	Diving, cross - country, athletics, swimming, softball, basketball and volleyball	IG (35)	19 (0.8)	IG: Health education sessions and flyers	IG: F2F (in person) + material delivery	For 8 weeks: 2×1 h, once a week (of eight health education sessions)	Female athlete requirements, macronutrient distributions, supplements, nutrition beliefs and myths; guidelines for healthy approaches to weight management.	NR	NKQ: AD	No significant changes were detected in nutrition knowledge.
		CG (35)		CG: Meeting without treatment	CG: F2F (in person)					
Abood et al., 2004 (USA)[9]	IG: Soccer	IG (15)	IG: 19.6 (1.0)	IG: Nutrition education sessions + workshops (diet record analysis and planning of meal)	IG: F2F (in person)	For 8 weeks: 6×1 h, once a week (nutrition education sessions) 2×1 h, once a week (workshops)	Energy, carbohydrate, fat, protein, fluids, calcium, iron and zinc, diet record analysis, application of nutrition principles, eating on the road, eating problems and solutions.	NR	Dietary intake: 3-day food record NKQ + SEQ: AD	Participants in the intervention group significant increase in nutrition knowledge, self-efficacy ($p < 0.05$) and the overall number of positive dietary changes ($p < 0.03$).
	CG: Swimming	CG (15)	CG: 19.4 (1.2)	CG: Meeting without treatment	CG: F2F (in person)					
Chapman et al., 1997 (USA)[45]	Softball	IG (37)	14–18 years	IG: Nutrition education sessions, flyers and demonstrations	IG: F2F (in person ‡) + material delivery	2×45 min, once a week (nutrition education sessions)	Ergogenic, dehydration, pre-competition meal, energy sources, vitamin and mineral supplements and weight control.	NR	Dietary intake: 24 h dietary recall NKQ + NAQ: Mod (Werblow et al., 1978)	Participants in the intervention group significant increase in nutrition knowledge ($p < 0.01$). There was no significant changes in dietary intake and food choice.
		CG (35)		CG: NT	CG: NT					
Gonçalves et al., 2014 (Brazil)[25]	IG: Indoor soccer and handball	IG (10)	IG: 13.2 (0.8) and 12–15 years	IG: Nutrition education sessions and flyers (Food pyramid)	IG: F2F (in person) + material delivery	1×10 min (nutrition education sessions)	Food pyramid adapted to physically active adolescents, the pyramid food groups and the recommendations.	NR	NKQ: Mod (Lima et al., 1985; Triches et al., 2005)	After the intervention, both groups showed a significant increase in nutrition knowledge ($p < 0.001$).
	CG: Volleyball and basketball	CG (17)	CG: 13.6 (0.7) and 12–15 years	CG: Flyers (Food pyramid)	CG: Material delivery					

Table 3. (*Continued*)

Heikkilä et al., 2019 (Finland)[60]	Endurance athletes (cross-country skiing, biathlon, orienteering, endurance running and race-running, triathlon)	IG (17)	18.0 (1.4) and 16–20 years (female and male)	IG: Nutrition education sessions (lectures, discussions, exercises, and individual and group work), dietary counselling session (individual feedback about food intake and recommendations) and APP (mobile app on smartphone)	IG: F2F (in person)	3 × 90 min, once a week (nutrition education sessions) 2 meetings, at the beginning and after the follow-up (dietary counselling session) 4 days (Mobile app use)	Importance of nutrition for athletic performance, energy requirements, fluids, carbohydrates, fat, and protein (sources, quality, timing, trends) from the viewpoint of endurance athletes, certain minerals and vitamins, supplements and challenges (eating on competition days, eating on the road, disordered eating, and weight control).	Nutritionist	Dietary intake: 3-day food record NKQ: Mod (Heikkilä et al., 2018)	Significant increase in nutrition knowledge in both groups ($p < 0.001$). Results on dietary intake were not reported by sex.
		CG (18)		CG: Nutrition education sessions (lectures, discussions, exercises, and individual and group work), dietary counselling session (individual feedback about food intake and recommendations)	CG: F2F (in person)					
Tektunalı et al., 2024 (Turkey)[12]	Football, basketball and volleyball	IG (45)	IG: 17.1 (1.5) and 15–18 years	IG: Nutrition education sessions and flyers	IG: F2F (in person) + material delivery	6 × 60 min once a week (nutrition education sessions)	Energy metabolism in sports, energy balance, nutrition before and after training, low energy availability, macro and micronutrients, hydration, and supplements.	Registered dietitian	Dietary intake: 3-day food record NKQ: Mod (Zinn et al., 2005) Body composition: weight, height, BMI, and body fat mass	Significant increase in total energy ($p < 0.005$), carbohydrate ($p = 0.01$), protein ($p = 0.01$) and fat intake ($p = 0.02$). Significant increase in nutrition knowledge in the intervention group ($p < 0.005$). After the intervention, a significant increase in BMI was observed ($p = 0.01$). The percentage of body fat increased significantly ($p = 0.03$).
		CG (38)	CG: 17.2 (2.6) and 15–18 years	CG: NT	CG: NT					
Patton-Lopez et al., 2018 (USA)[23]	Soccer	IG (94)	14.9 (0.9) and 14–19 years	IG: Nutrition education sessions, workshops (grocery shopping, cooking and gardening) and flyers (recipes/tips to meet sport fuel and nutrition need)	IG: F2F (in person) + material delivery	For 2 years : 7 × 30 min (nutrition education sessions) 3 × 1–1.5 h (workshops)	Hydration, fueling pre and during exercise, recovery nutrition, body composition and image, maintaining muscle and staying well, eating well while eating out.	Registered dietitian nutritionist	NKQ: No mod (Walsh et al., 2011)	Significant increase in nutrition knowledge in the intervention group ($p < 0.001$).
		CG (44)		CG: NT	CG: NT					

(*Continued*)

Table 3. (*Continued*)

Study demographics				Intervention					Outcomes	
Reference	Sport	Sample size (n)	Age in years: Mean (SD) and/ or rank	Description	Mode of delivery	Duration and frequency	Nutrition curriculum	Facilitator	Outcomes	Key findings
Torres-McGehee et al., 2011 (USA)[59]	Dancers	IG (21)	IG: 19.2 (1.2) and 18–25 years	IG: Nutrition education sessions and guide (sports nutrition)	IG: F2F (in person) + material delivery	For 4 weeks: 8 × 45 min, twice a week (nutrition education sessions)	The effects of anabolic steroids and other drugs, effects of alcohol on athletic performance, calcium needs sports nutrition, exercise, depression and consequences of disordered eating.	Researcher †	NKQ: No mod (Shifflett, et al., 2002)	Significant increase in nutrition knowledge in the intervention group ($p = 0.01$).
		CG (19)	CG: 19.1 (1.0) and 18–25 years	CG: NT	CG: NT					

IG, intervention group; CG, control group; SD, standard deviation; F2F, face to face; NT, no treatment; NR, not reported; NKQ, nutrition knowledge questions; NAQ, nutrition attitudes questions; SEQ, self-efficacy questions; AD, author designed instrument; Mod, modified pre-existing instrument; No mod, used original instrument without modification.
†Additional information provided by author
‡Deduced by the researcher

two population groups and reported the results separately (ballet dancers and athletes)[51].

Regarding the outcomes, in single-arm studies ($n = 20$), fifteen assessed dietary intake[10,11,26,43,47,48,51,52,54–58,60,61], three assessed adherence to the Mediterranean diet[26,27,55], thirteen assessed nutrition knowledge[10,11,26,27,46,48–50,53,54,56,58,60] and eight assessed body composition[10,26,43,47,51,52,60,61]. In double-arm studies ($n = 8$), three evaluated dietary intake[9,12,45], eight evaluated nutrition knowledge[9,12,23,25,44,45,59,62], and one evaluated body composition[12].

Intervention characteristics

Facilitator

The facilitator of the educational intervention was reported in 75% ($n = 21$) of the studies, with professional nutritionists or dietitians ($n = 17$) being the most common providers. The remaining 25% ($n = 7$) of the studies did not specify the intervention facilitator.

Description of the intervention

Intervention strategies varied across studies. Eighteen studies of twenty-eight implemented nutrition education sessions, twelve conducted individual nutrition consultations, eleven organised workshops, and two employed gamification. Among double-arm studies, only one included individual nutrition consultation. Several studies combined intervention modalities; for instance, three studies integrated both group educational sessions and nutrition consultations. Most control groups received no treatment; only two studies reported holding meetings with control participants, without specifying the content. Regarding intervention scope, two studies[26,27] included parents while three studies[12,23,26] involved coaches. From a conceptual perspective, some interventions were grounded in theoretical learning models ($n = 3$)[49,50,62] and were based on behaviour change theories ($n = 6$)[9,11,46,49,54,62]. The remaining studies do not report on the theoretical frameworks used to design the intervention.

Mode of delivery

All studies employed face-to-face delivery modalities, with eighteen explicitly reporting in-person intervention, one reporting an online intervention and one using a mixed approach. Eight studies did not report the delivery mode. Two studies[45,48] were inferred to be face-to-face because their publication dates predated the widespread adoption of the internet. In addition, thirteen studies reported providing supplementary materials to participants.

Nutrition education topics

Nutrition education topics varied across studies. General principles of sports nutrition were addressed in twenty-two studies, while twelve studies included individual nutrition plans or weight control strategies, and eighteen studies included a combination of nutrition topics covering energy consumption, macronutrients, micronutrients and hydration principles. Other incorporated topics were: the use of supplements ($n = 11$); eating away from home ($n = 9$); addressing eating problems and their solutions ($n = 8$); understanding food groups and dietary guidelines ($n = 8$); managing food portions, meal frequency and timing ($n = 4$); debunking myths and addressing beliefs ($n = 2$); exploring principles of the Mediterranean diet ($n = 1$). It should

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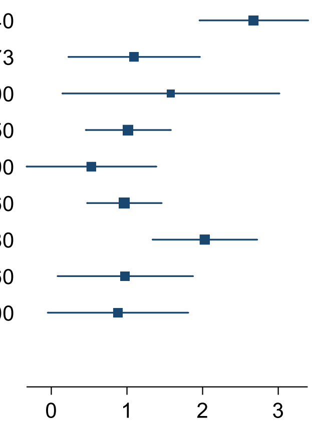
Study	Post-intervention N	Post-intervention Mean	Post-intervention SD	Pre-intervention N	Pre-intervention Mean	Pre-intervention SD	Hedges's g with 95% CI	p value
Collison et al., 1996 (48)*	28	90.00	6.30	28	68.30	9.40	2.67 [1.96, 3.39]	<0.0001
Valliant et al., 2012 (10)*	11	57.30	11.10	11	44.91	10.73	1.09 [0.23, 1.96]	0.0141
Martinelli et al., 2013 (54)*	4	40.00	2.60	4	24.25	12.00	1.58 [0.15, 3.01]	0.0389
Gonçalves et al., 2014 (25)*	27	67.80	19.00	27	50.40	14.50	1.01 [0.46, 1.57]	0.0004
Daniel, et al., 2016 (49)	10	63.00	11.80	10	57.00	9.90	0.53 [-0.33, 1.38]	0.2297
Heikkilä et al., 2019 (60)*	35	85.00	7.60	35	77.60	7.60	0.96 [0.47, 1.45]	0.0001
Aguilo et al., 2021 (26)	24	51.00	2.10	24	45.90	2.80	2.03 [1.34, 2.72]	<0.0001
Zaman et al., 2021 (11)*	10	84.00	5.60	10	76.00	9.60	0.97 [0.08, 1.87]	0.0330
Tan et al., 2022 (56)	9	73.10	10.60	9	63.60	10.00	0.88 [-0.05, 1.80]	0.0641



*Differences between pre and post-intervention data were statistically significant (p<0,05) according to the authors.

Fig. 2. Forest plot and effect sizes of changes in nutritional knowledge score (expressed as percentage) from pre- to post-intervention for single-arm studies.

be noted that only one study[59] addressed the topic of alcohol consumption, specifically its effects on athletic performance.

It should be noted that only three studies[26,49,62] reported considering the participants' prior knowledge when deciding on the topics of the intervention.

Duration

The number of educational sessions varied from one to twelve during the intervention period. The duration of each session ranged between 10 and 480 min (1-d educational session; 8.00 to 17.30). The total duration of the interventions varied from 1 d to 2 years.

Outcomes

Nutrition knowledge

Nutrition knowledge was assessed in twenty-one studies (thirteen single-arm and eight double-arm design studies). As reported by the authors, in sixteen studies[9–12,23,25,45,46,48–50,53,54,59,60,62], the nutrition knowledge of the participants showed significant increases. Regarding the assessment instruments used, six studies employed a questionnaire created specifically for their research[9,27,44,53,54,60], seven studies utilised an original questionnaire[10,11,23,46,49,50,59] and eight studies used an original questionnaire with modifications[9,12,25,26,45,56,58,62]. Questionnaire validation was reported in sixteen studies (76·2%). However, validation was not documented in five studies: three using author-designed tools[25,45,60], and two employing modified versions of original instruments[27,53]. Only four studies[23,46,60,62] assessed the maintenance of knowledge over time, reporting significant increases both in the immediate post-intervention period and at the follow-up period.

Facilitators' qualifications and knowledge dissemination methods were reported in varying details across studies. Among the twenty-one studies, twelve indicated that registered dietitians or nutritionists were responsible for planning and delivering the educational interventions, potentially ensuring that participants received quality nutrition information, two reported a researcher/professor as facilitators, and one utilised a dietetics student. Six studies did not report this information.

When comparing the results of nutrition knowledge from single-arm studies (Fig. 2), seven studies were included, while six[27,46,50,53,58,60] were excluded owing to the lack of necessary data for calculations. In addition, two double-arm studies[25,62] were included, considering that the authors reported pooled data from female athletes who participated in both arms, as no statistically significant differences between the two interventions were reported. It is worth noting that in the study by Heikkilä *et al.*[62], the standard deviation (SD) by sex was not provided; therefore, to include their results in the analysis, we assumed it was the same as that of the total sample, which included both men and women. The weighted mean scores for nutrition knowledge increased from 60·7% (9·7) before the intervention to 72·6% (10·4) after the intervention, resulting in an average improvement of 11·9 (10·1) percentage points. The effect size was calculated for these nine studies (Fig. 2). Seven studies[10,11,25,48,54,62] reported significant changes, of which six had a large effect size (ES >0·8).

For the comparison of nutrition knowledge outcomes from double-arm studies, all studies were included except those included in the analysis of the single-arm studies. In the study by Patton-Lopez *et al.*[23], the SD was not reported by sex. To include these results in our analysis, we assumed the SD for females was equivalent to that of the total sample, which comprised both males and females, because no differences in knowledge distribution were detected between both sexes. The weighted mean score of nutrition knowledge before and after the nutrition education intervention was 53·0% (20·0) and 62·4% (20·0), respectively, with a mean increase of 9·4% (20·0) from pre-intervention. The weighted mean scores of knowledge before and after the test for the control groups were 50·7% (19·1) and 50·6% (18·7), respectively, indicating an average variation of −0·1% (18·9). The effect size was calculated in all studies (Fig. 3). Three out of the five studies that reported significant changes had a large effect size (ES >0·8)[9,45,59].

Dietary intake

We collated findings from eighteen studies (fifteen single-arm and three double-arm design) exploring the impact of nutrition

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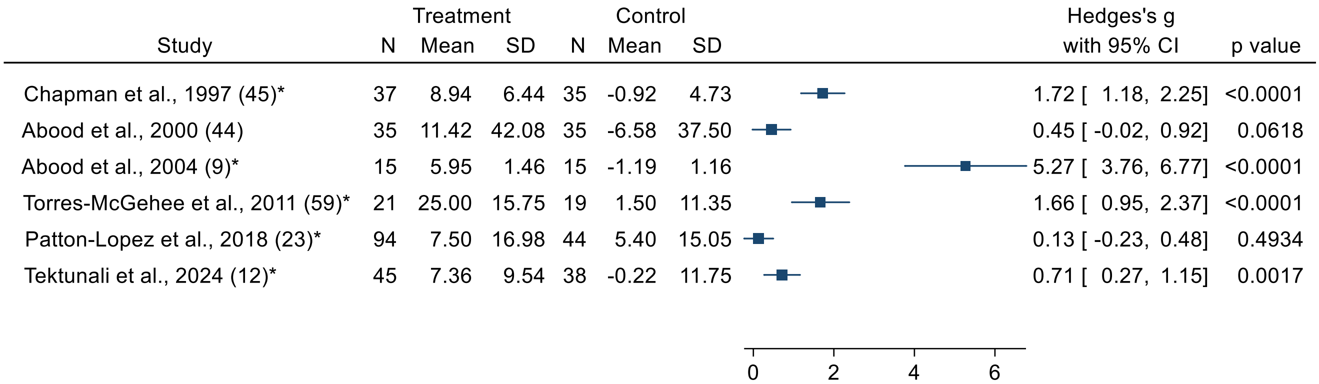

* Differences between control and intervention groups were statistically significant (p<0,05) according to the authors.

Fig. 3. Forest plot and effect sizes of changes in nutritional knowledge score (expressed as percentage) of treatment and control groups for double-arm studies.

education interventions on dietary intake among female athletes. The primary assessment methods included the 3-d dietary record, utilised in eleven studies[9–12,43,47,48,56,60–62], followed by the consecutive 7-d dietary record in three studies[51,52,54], a 24-h dietary recall in three studies[26,45,55], a food frequency questionnaire in one study[26] and an eating habits questionnaire in two studies[57,58]. It should be noted that the study published by Aguilo *et al.*[26] employed both 24-h recall and the food frequency questionnaire. Regarding the implementation of dietary records (3- and 7-d records), verbal and/or written instructions were provided to subjects prior to recording in seven of the thirteen studies[9–11,43,47,48,54]. Regular contact to verify accuracy and provide clarifications was reported in seven studies[10,43,48,51,52,54,56], while seven studies provided photographs or illustrations to guide portion sizes[9,11,51,52,56,60,61], and one study utilised a mobile application for image-based record submission[11].

In relation to nutrient intake (evaluated in sixteen studies), all studies assessed macronutrient intake, while seven specifically examined fibre intake[9,26,47,51,52,55,62]. Micronutrient intake, focusing primarily on vitamin C, iron, and calcium, was evaluated in nine studies[9,12,26,47,51,52,54–56]. Alcohol consumption was assessed in three studies[9,54,60].

In addition to assessing changes in dietary intake, only two studies reported the number of participants meeting nutrition recommendations[47,61]. Both studies provided data on the percentage of participants who met macronutrient intake recommendations, while only one study reported the proportion of participants meeting micronutrient recommendations[47].

Significant changes in nutrient intake were reported in nine out of thirteen single-arm design studies[10,11,26,43,47,51,52,55,60] and in two of three double-arm design studies[9,12].

Regarding observed changes in dietary intake, seven studies reported an increase in energy intake[10–12,26,43,51,52], eight reported an increase in carbohydrate intake[10–12,26,43,51,52,55], seven observed an increase in protein intake[10–12,43,47,51,52] and three reported an increase in fat intake[11,12,51]. Micronutrient intake increased in four studies[26,47,52,55], and one study reported a significant decrease in alcohol consumption[60]. Out of the two studies that evaluated eating habits, one of them reported significant changes[57]. It should be noted that while Heikkilä *et al.*[62] evaluated dietary intake, the data were not disaggregated by sex. Consequently, this study was excluded from our analysis of dietary intake outcomes.

Finally, it is important to note that energy availability was assessed in only two of the included studies[51,52], both conducted within the same research project, with the second being an expanded version of the first. The aim of this project was to evaluate the influence of a nutritional education intervention on the menstrual cycle of young athletes with amenorrhea or oligomenorrhea, an approach that is closely aligned with the assessment of energy availability.

Body composition

Changes in athletes' body compositions were evaluated in nine studies (eight single-arm and one double-arm). All studies measured body fat percentage[10,12,26,43,47,51,52,60,61], mainly using bioimpedance[10,43,47] and plethysmography[12,26,51,52,60,61]. Within the studies reporting significant changes, two employed air displacement plethysmography with the Bod-Pod body composition system[10,43], while one study used a multi-frequency bioimpedance body composition analyser[26]. The duration of the interventions in these three studies ranged from 4 months[10,43] to 8 months[26] and all included individual dietary counselling.

Among the nine studies evaluating body composition changes, three single-arm studies reported significant changes, including decreases in body fat percentage[10,26,43] and increases in lean mass percentage[10,26]. The sole double-arm design study assessing body composition changes reported significant increases in both BMI ($p = 0{\cdot}01$) and fat mass ($p = 0{\cdot}03$)[12].

Other variables of interest

Adherence to the Mediterranean diet (MD) was evaluated in three studies using the KIDMED Index[26,27,55]. Four studies assessed nutrition attitude[11,45,50,53], while four examined the risk of eating disorders[12,44,59,60]. Two studies evaluated body dissatisfaction[49,60]. Single studies assessed self-esteem[44], self-efficacy[9], stage of intention to change eating behaviour[49] and restrictive dietary behaviours to lose weight[46].

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Regarding adherence to the MD, two studies[27,55] reported significant increases in KIDMED Index scores, indicating an improvement in the proportion of participants classified as having good adherence to the MD.

Study quality

Methodological quality was assessed for all studies (Supplementary Tables S3 and S4). Single-arm studies scored between 7 and 21 points, with a mean of 14·9 (3·6) points, while double-arm studies scored between 18 and 24 points, with a mean of 21·4 (1·8) points. On the basis of these results, three studies were classified as poor quality, ten as fair quality, thirteen studies as good quality and two studies as excellent quality.

Discussion

To our knowledge, this systematic review is the first to evaluate the effectiveness of different nutrition education interventions on nutrition knowledge, dietary intake and body composition on female athletes. Overall, the results indicate that the implemented interventions significantly improved nutrition knowledge (fifteen of twenty-one studies that assessed this variable) and dietary intake (twelve of eighteen studies). Significant changes in body composition were reported in only four of the nine studies, the results suggest that nutrition education can be an effective tool for promoting healthier dietary behaviours in this population. These outcomes reinforce the importance of developing and implementing targeted educational interventions for female athletes, considering that their nutritional needs and physiological responses may differ from those of male athletes. Factors such as hormonal fluctuations throughout the menstrual cycle, the higher risk of relative energy deficiency in sport (RED-S) and the high prevalence of micronutrient deficiencies, including iron and calcium, can negatively impact both athletic performance and long-term health. Despite these specific considerations, many current sports nutrition strategies continue to be based primarily on evidence derived from male populations, highlighting the urgent need for interventions and research specifically focused on female athletes.

The heterogeneity of educational interventions complicates direct comparisons between studies and makes it difficult to determine the most effective type of intervention or method worth replicating in future research. Moreover, the lack of specific details regarding the characteristics of the interventions, such as their duration, exact content, methodology and the profile of the professionals delivering them, limits the interpretation of the results. It is important to verify that the contents of the educational intervention consider the specific needs of female athletes. In addition, the scarce reporting on the theoretical underpinnings of the interventions, including learning models and behaviour change theories, further constrains the understanding of the mechanisms through which these interventions may have influenced outcomes. This lack of information not only prevents drawing definitive conclusions but also hinders the practical application of the evaluated strategies, thereby reducing their potential impact in real-world settings. Therefore, it is essential for future studies to provide detailed descriptions of their interventions to enhance replicability and optimise the design of evidence-based educational strategies. The effectiveness of an intervention is defined by its ability to produce the desired outcome, which requires adequate description for evaluation[22]. Therefore, studies should include detailed reports of intervention elements such as curriculum, facilitator qualifications, delivery mode, duration, frequency and total session count. In our review, fifteen of twenty-eight studies reported session durations, and twenty-one of twenty-eight indicated intervention frequency.

Notably, none of the studies included in our review cited existing guidelines for intervention planning and design. This oversight is common, as observed by Hand *et al.*[63]. Their 'Guide for Effective Nutrition Interventions and Education (GENIE)', published in 2015, offers a checklist to aid researchers and programe planners in designing higher quality and more consistent educational interventions. A key GENIE recommendation is the involvement of field experts in interventions. However, in seven of our reviewed studies, this aspect was unclear owing to lack of information about the professionals responsible for planning and delivering the nutrition education.

The interventions in the included studies varied in their delivery mode, duration and frequency. Most were conducted in face-to-face group settings, though eight studies did not specify whether delivery mode was in person or online. Regarding the type of intervention, the majority involved group nutrition education sessions, often supplemented with workshops and the provision of educational materials. Solly *et al.*[64], investigating the preferences of 124 athletes regarding nutrition education, found that 25% of participants preferred a combination of group and individual in-person sessions, while only 13% favoured exclusively online delivery. In addition, participants expressed preference for practical activities and discussions with a facilitator. These findings highlight the importance of considering athletes' preferences when designing nutrition education interventions to maximise their engagement and effectiveness. It would also be relevant to explore whether female athletes have specific preferences in this area. While studies such as that of Solly *et al.*[64] analyse athletes' preferences in general, future research should examine whether gender-specific factors influence participation and the effectiveness of nutrition education in female athletes.

Group-based nutrition education sessions can offer benefits in terms of human and time resources, potentially enhancing cost-effectiveness. The second most common type of intervention was dietary counselling or feedback on dietary intake. Among the eleven studies that implemented this approach, 72·7% reported significant changes in dietary intake, compared with 57·1% of the seven studies that did not employ it. These findings suggest that dietary counselling is an effective strategy for modifying dietary intake. A review by Fiorina *et al.*[28], which examined the effect of nutrition counselling on athletes, concluded that this intervention type induces positive and measurable behavioural effects in athletes, improving nutrition knowledge and promoting the adoption of appropriate eating patterns.

Regarding duration, interventions were generally short-term (typically less than 4 weeks), with sessions usually lasting less than 1 h. Total contact time was less than 350 min for interventions where this could be calculated. However, intervention time could only be determined for sixteen of the twenty-eight studies, as 43% reported only session frequency or total intervention duration in months, without specifying individual session lengths. This situation mirrors findings by Boidin *et al.*[8], where intervention duration could be quantified in minutes for only three of twelve studies assessing the effectiveness of nutrition education programmes on athletes' dietary intake.

The sample sizes varied widely across studies, ranging from 4 to 138 participants. Only 29% of the included studies were RCTs,

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incorporating both an intervention group and a control group. Despite the limited number of studies with a RCT design, the majority (87·5%) were classified as having good or excellent methodological quality. This finding contrasts with the results reported in the review by Sánchez *et al.*[37] in their review of male and female athletes, where five of seven studies with both intervention and control groups were categorised as having poor or fair quality.

Most studies in our review employed single-arm designs (71%), with over half classified as having poor or fair methodological quality (60%). This aspect may influence the interpretation and application of the study results, affecting their external validity. Therefore, it is essential to improve methodological quality in future research through more rigorous designs to obtain more robust, reliable and applicable findings.

Effects of nutrition education interventions on nutrition knowledge

In this review, the majority of studies assessing nutrition knowledge reported significant increases (15 of 21 studies) following nutrition education interventions. In nine studies where effect sizes could be calculated, a large effect size (>0·8) was demonstrated. This finding suggests a substantial increase in nutrition knowledge, indicating effective understanding by the athletes of the nutrition concepts presented.

As established, study tools should undergo sufficient validation to ensure result reliability[20]. In our review, 5 of 21 studies (23·8%) did not report validating their measurement instruments. Comparatively, Tam *et al.*[36] found that 53·1% of included studies used a knowledge questionnaire without prior validation. The lack of prior validation of the questionnaire can be troublesome for several reasons. First, it introduces uncertainty about whether the questionnaire actually measures the intended construct (in this case, knowledge of sports nutrition) and whether it can effectively discriminate between different levels of knowledge. Second, a lack of reliability may result in inconsistent and unstable results over time or other factors. These limitations not only undermine the precision and accuracy of the results obtained with the questionnaire but also hinder comparability with other studies. The use of non-validated questionnaires might be acceptable when assessing the acquisition of very specific and clearly defined knowledge (e.g. to find out whether athletes know which liquids to drink for hydration depending on the duration of exercise), but this is rarely the unique purpose of sports nutrition research. Usually, the aim is to assess general knowledge. However, including all the aspects of sports nutrition knowledge in a questionnaire is not feasible, so the selection of items and the vocabulary and wording used must be appropriate to the target group. Finally, the instrument should be validated in accordance with the construct of interest in order to demonstrate that the instrument meets the requirements mentioned above.

Remarkably, only 3 studies extended the educational intervention to include coaches. This is significant because athletes' lack of nutrition knowledge may be associated with coaches' insufficient understanding and misinformation[65]. The study published by Vázquez-Espino *et al.*[18] reported that young athletes most frequently cited family (57%) and coaches (49%) as their main sources of nutrition information, reinforcing the importance of the support staff's role in conveying knowledge in this area. Extending nutrition education to athletes' support personnel can be crucial for enhancing the comprehension and application of nutrition concepts within this group[66]. This approach presents an important consideration for future research[67].

Effects of nutrition education interventions on dietary intake

Most studies evaluating dietary intake (twelve of eighteen) reported significant increases following nutrition education interventions. It is noteworthy that various methods were used to assess athletes' intake. While weighed food records are more precise, they present significant practical challenges. Athletes' irregular training and eating schedules often make weighing each food and drink consumed difficult owing to time constraints and patience limitations[68]. Consequently, food records are the most used method for dietary assessment in research; however, self-reported records may underestimate actual intake[69]. To address this limitation, it is crucial to conduct an initial meeting with participants to explain procedures in detail and emphasise the importance of accurately recording all foods and beverages consumed throughout the day[70]. The use of information technologies, such as capturing images via mobile phones, have been reported to potentially enhance the accuracy of participant-recorded data[71–74]. In addition, regular researcher–participant contact should be maintained to ensure data accuracy. These practices were implemented in only seven of the thirteen studies that utilised dietary records, highlighting an area for improvement in future research. In addition to the variety of methods used to assess dietary intake, it is important to acknowledge the limitations associated with certain approaches. In the study published by Sahnoune *et al.*[55], a 24-h recall was used to assess micronutrient intake, a method that is inadequate for evaluating habitual intake. This method captures data for just 1 d, which may not accurately reflect the usual dietary patterns of athletes. Because athletes' diets tend to vary from day to day, for example, variations due to periodised training cycles, a single-day recall may miss fluctuations in nutrient intake caused by intra-individual variability. For more accurate estimates of habitual energy, macro- and micronutrient consumption, a dietary recording period of 3–7 d is recommended[68].

Furthermore, it is crucial to estimate the proportion of participants not meeting nutrition requirements, rather than solely focusing on mean intake values, as this approach provides a more comprehensive assessment of the intervention's effectiveness in the studied population[75]. Unfortunately, most studies only reported mean intake values, with some comparing them to age-specific recommendations for the sample. Only one study[61] reported the percentage of athletes meeting nutrition requirements.

Of the eleven studies that evaluated both nutritional knowledge and dietary intake, nine reported significant improvements in knowledge, and five of them also showed significant changes in dietary intake. Previous studies have demonstrated that good nutritional knowledge is associated with improvements in dietary behaviour[6,20,76,77]. However, it is important to consider that food choices are influenced by various factors, such as food availability, socioeconomic conditions, family and community resources, and food literacy[78]. The latter encompasses the set of knowledge, skills and behaviours necessary to plan, manage, select, prepare and consume food appropriately[78]. Therefore, while improving nutritional knowledge is a key step, it does not necessarily guarantee changes in dietary habits.

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Effects of nutrition education interventions on body composition

Optimal body composition is essential for athletic performance, as it enhances physical fitness and reduces the risk of injuries[5]. Therefore, it is important to investigate whether nutritional education interventions can positively influence athletes' body composition.

Of the nine studies assessing changes in body composition, significant improvements were observed in three. Body composition can be assessed using various methods, such as bioimpedance, dual-energy X-ray absorptiometry and skinfold measurements, which often complicates direct comparisons[79].

A review by Sánchez-Díaz *et al.*[37], which included athletes of both sexes participating in team sports, found that five studies evaluated the effects of nutrition education interventions on body composition, with three reporting significant changes (reduction in fat mass). It is relevant to mention that two of the studies reporting significant changes in that review were also included in our review[10,43].

The lack of changes observed in most studies evaluating body composition may be attributed to the athletes having optimal body composition variables at baseline. This could be related to their physical condition, which is necessary for managing training sessions and competition[37].

Limitations and future directions

This review presents some limitations that influence the interpretation of reported results. First, the variability in nutrition education strategies complicates inter-study comparisons and identification of the most effective educational methods for improving the studied variables. Second, heterogeneity in methodologies for assessing nutrition knowledge, dietary intake and body composition limits the integration of data and the ability to draw clear conclusions. The use of different measurement instruments, assessment scales or methods of analysis can introduce biases and affect the reliability and validity of results. Third, small sample sizes in some studies limit their statistical power and generalisability to the broader population of female athletes, impacting the robustness of the observed findings. Fourth, the scarcity of studies incorporating both intervention and control groups is concerning, as such designs offer a more robust level of evidence compared with single-arm studies. Fifth, thirteen of twenty-eight studies were rated as having poor to fair quality, highlighting the need for improved study designs and methods used in intervention studies. Sixth, tracking attendance at planned educational interventions is crucial for evaluating the fidelity of interventions, assessing outcome impacts, and identifying potential barriers. However, this aspect was reported in only fifteen of twenty-eight studies. Lastly, there is a possibility that studies with non-significant effects in the interventions may not have been published.

Conclusions

Nutrition education interventions are generally considered an effective strategy to improve nutrition knowledge and dietary intake in female athletes. However, the heterogeneity of the intervention strategies applied (modality of delivery, frequency and duration) makes it challenging to identify the specific characteristics that ensure the success of a nutrition education intervention in meeting its established objectives. This indicates that nutrition education programmes should consider the needs of female athletes.

Future research should prioritise more robust study designs, appropriate sample sizes and inclusion of both intervention and control groups, ideally employing RCT designs. This approach will enable a more precise evaluation of intervention effects and help reduce the risk of bias. Furthermore, educational intervention designs should incorporate recommendations from established guidelines such as the Guide for Effective Nutrition Interventions and Education (GENIE)[63], which assists in planning, self-assessment and enhancing nutrition education programmes.

Finally, advancing the standardisation of methodologies for assessing nutrition knowledge, dietary intake and body composition in athletes through consensus guidelines or expert recommendations is crucial. Ensuring the psychometric validation of applied questionnaires will improve comparability across studies and enhance the quality of the collected data.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0954422425100152.

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