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The Role Of Macronutrient Intake On Increasing Vo₂Max In Athletic Learning In Schools: A Systematic Literature Review

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A. Conception and design of the study; **B.** Acquisition of data; **C.** Analysis and interpretation of data; **D.** Manuscript preparation; **E.** Obtaining funding

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ABSTRACT

Background: VO_2max is one of the most important indicators of cardiorespiratory fitness and plays a crucial role in supporting students' performance during athletics learning in schools. Adequate macronutrient intake, including carbohydrates, proteins, and fats, is essential for energy production, physiological adaptation, and aerobic endurance development. However, evidence regarding the role of macronutrient intake in improving VO_2max among school-aged students remains fragmented. Objective: This study aimed to systematically review and synthesize conceptual and empirical evidence regarding the role of macronutrient intake in enhancing VO_2max during school-based athletics learning. Methods: A Systematic Literature Review (SLR) was conducted following the PRISMA 2020 guidelines. Literature was retrieved from Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, SINTA, and Garuda databases. From 186 identified articles, 25 studies published between 2016 and 2025 met the inclusion criteria and were analyzed. Data were synthesized using a narrative thematic approach. Results: The findings revealed that 88% of the reviewed studies reported a positive relationship between adequate macronutrient intake and VO_2max improvement. Carbohydrates showed the strongest contribution, with 92% of studies demonstrating significant benefits for aerobic capacity, followed by protein (84%) and fat (72%). Intervention studies reported VO_2max improvements ranging from 11% to 16% when balanced macronutrient intake was combined with structured athletics training. Conceptually, the findings support the Energy Availability Theory, Glycogen Depletion Theory, Muscle Protein Synthesis Theory, and Fat Oxidation Theory. Conclusion: Adequate macronutrient intake is a key determinant of VO_2max development and cardiorespiratory fitness in school athletics learning. Integrating nutrition education with athletics programs can optimize students' physical fitness, learning participation, and overall health outcomes.

Keywords : Macronutrient Intake; VO_2max; Cardiorespiratory Fitness; Athletics Learning; Systematic Literature Review

INTRODUCTION

Physical fitness is a fundamental component of educational outcomes in school-based physical education, particularly in athletics learning activities that require high cardiorespiratory endurance. One of the most widely accepted indicators of cardiorespiratory fitness is maximal oxygen uptake (VO_2max), which reflects the body's capacity to transport and utilize oxygen during prolonged physical activity. Higher VO_2max values are associated with better endurance performance, improved learning participation, reduced fatigue, and enhanced health status among students (Everett et al., 2025). In recent years, concerns have emerged regarding the

declining physical fitness levels of school-aged children and adolescents. Several studies have reported that inadequate nutritional intake, sedentary lifestyles, and insufficient physical activity contribute significantly to reduced aerobic capacity among students and young athletes. Macronutrient intake, consisting of carbohydrates, proteins, and fats, plays a critical role in supporting energy production, muscle adaptation, and physiological recovery processes that directly influence VO_2max development (Sandi et al., 2024).

From a physiological perspective, carbohydrate availability serves as the primary energy substrate during moderate-to-high intensity exercise. According to the Glycogen Depletion Theory, inadequate carbohydrate stores reduce endurance capacity because skeletal muscles rely heavily on glycogen during aerobic exercise. Meanwhile, protein intake supports muscle protein synthesis, mitochondrial adaptation, and recovery, whereas healthy fat intake contributes to long-duration energy metabolism and hormonal regulation. Therefore, balanced macronutrient consumption is essential for optimizing aerobic fitness development in adolescents participating in athletics programs (Jeukendrup, 2017; Burke et al., 2021). School athletics learning often emphasizes training methods and motor skill acquisition while overlooking nutritional factors that may substantially influence physiological adaptation. This gap is particularly relevant because students are in a period of rapid growth and development, during which nutritional requirements increase considerably. Several investigations have demonstrated that energy deficiency and inadequate macronutrient consumption negatively affect cardiovascular endurance, recovery rate, and exercise performance among youth populations (Everett et al., 2025; Sandi et al., 2024). Consequently, understanding the role of macronutrient intake in improving VO_2max during school athletics learning is essential to develop evidence-based nutritional strategies that support both educational and athletic outcomes.

The relationship between nutrition and aerobic performance has been extensively discussed within sports nutrition and exercise physiology literature. The Energy Availability Theory proposes that adequate dietary intake is necessary to maintain physiological functions while supporting exercise adaptation. When energy intake is insufficient, physiological systems prioritize survival processes rather than performance enhancement, resulting in reduced training adaptations and lower aerobic fitness. Recent studies consistently highlight the importance of carbohydrates in enhancing endurance performance. Research among adolescent athletes revealed that carbohydrate intake positively correlates with physical fitness and aerobic capacity because glycogen availability improves exercise tolerance and delays fatigue onset (Gunawan et al., 2025). Similarly, investigations involving youth swimmers demonstrated that carbohydrate consumption significantly influences physical fitness indicators, including aerobic endurance and exercise performance. These findings align with the Classical Endurance Nutrition Model, which suggests that sufficient carbohydrate intake increases glycogen storage and supports sustained aerobic metabolism during exercise (Burke et al., 2019). Protein intake has also received considerable attention. According to the Muscle Protein Synthesis Theory, dietary protein supports skeletal muscle remodeling, mitochondrial biogenesis, and recovery following exercise. Recent evidence indicates that adolescents with adequate protein intake exhibit better training adaptations and improved physical fitness compared with those experiencing protein insufficiency (Gunawan et al., 2025).

Fat intake, although traditionally underestimated in youth sports nutrition, plays a crucial role in endurance exercise. The Fat Oxidation Theory explains that fats become increasingly important as exercise duration increases. Appropriate fat consumption supports hormonal balance, cellular function, and long-term energy provision. Studies have shown positive associations between adequate fat intake and physical fitness indicators among adolescent athletes (Gunawan et al., 2025). Beyond individual macronutrients, contemporary sports

nutrition research emphasizes integrated dietary approaches. Sandi et al. (2024) concluded that optimal nutritional status contributes significantly to cardiovascular endurance, metabolic efficiency, recovery quality, and athletic performance. Their literature review highlighted the synergistic effects of carbohydrate, protein, fat, hydration, and dietary planning on endurance development. Furthermore, nutrition intervention studies have demonstrated that deficiencies in energy, protein, and carbohydrate intake remain prevalent among adolescent athletes, potentially limiting aerobic fitness improvements despite regular training participation. Collectively, current evidence supports the proposition that macronutrient adequacy is a fundamental determinant of aerobic fitness and VO_2max development among adolescents engaged in sports and physical education activities.

Although numerous studies have examined sports nutrition and physical fitness, several important gaps remain unresolved. First, most previous investigations focus on competitive athletes rather than students participating in school-based athletics learning. Consequently, the applicability of existing findings to physical education contexts remains uncertain. Second, many studies evaluate general physical fitness rather than specifically examining VO_2max as the primary outcome variable. Since VO_2max represents the gold standard measure of cardiorespiratory endurance, more focused analysis is needed to understand how macronutrient intake influences this physiological parameter. Third, previous studies frequently analyze individual nutrients separately, particularly carbohydrates or protein intake, without comprehensively evaluating the combined influence of all three macronutrients on aerobic fitness adaptation. Fourth, evidence regarding adolescent populations remains fragmented. Existing literature includes athletes from swimming, football, basketball, and other sports, yet systematic synthesis specifically addressing school athletics learning is limited. Fifth, educational perspectives are rarely integrated into sports nutrition discussions. Most investigations emphasize athletic performance outcomes while neglecting the broader educational implications of improved aerobic fitness, such as enhanced participation, learning engagement, and health promotion. These gaps indicate the necessity of conducting a systematic literature review that synthesizes current evidence regarding the role of macronutrient intake in improving VO_2max within school athletics learning environments.

This systematic literature review aims to analyze, synthesize, and critically evaluate empirical and conceptual evidence regarding the role of macronutrient intake in improving VO_2max during athletics learning in schools. Specifically, this review seeks to: Examine the physiological mechanisms linking carbohydrate, protein, and fat intake with VO_2max enhancement. Identify empirical evidence concerning the influence of macronutrient consumption on aerobic fitness among adolescents. Evaluate the relevance of sports nutrition principles within school athletics learning contexts. Develop an integrated conceptual framework connecting nutrition, aerobic fitness, and educational outcomes. The novelty of this review lies in its comprehensive integration of sports nutrition science, exercise physiology, and physical education perspectives. Unlike previous reviews that primarily focus on elite athletes or general physical fitness, this study specifically addresses VO_2max development in school athletics learning and synthesizes evidence related to all major macronutrients simultaneously. Furthermore, it proposes a conceptual linkage between nutritional adequacy and educational outcomes through improved cardiorespiratory fitness.

Based on theoretical and empirical evidence, macronutrient intake constitutes a crucial determinant of aerobic fitness and VO_2max development among adolescents. Carbohydrates support glycogen availability and endurance performance, proteins facilitate muscular and mitochondrial adaptation, while fats contribute to long-duration energy metabolism and physiological regulation. Although substantial evidence exists regarding nutrition and athletic

performance, limited research has systematically synthesized the role of macronutrients in enhancing VO_2max within school athletics learning environments. Therefore, this systematic literature review is expected to provide a comprehensive scientific foundation for developing nutrition-based strategies that optimize cardiorespiratory fitness, learning participation, and athletic achievement among students.

METHODS

This study employed a Systematic Literature Review (SLR) design to synthesize and critically evaluate scientific evidence regarding the role of macronutrient intake in improving VO_2max during athletics learning in school settings. A systematic review is considered one of the highest levels of evidence because it applies a transparent, rigorous, and reproducible approach for identifying, evaluating, and synthesizing relevant studies (Page et al., 2021). The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological rigor, transparency, and reliability in reporting evidence. Conceptually, this review was grounded in the Energy Availability Theory, Glycogen Depletion Theory, and Muscle Protein Synthesis Theory, which explain how adequate intake of carbohydrates, proteins, and fats influences physiological adaptations related to aerobic capacity. According to Burke et al. (2019), carbohydrates serve as the primary fuel source during endurance exercise by maintaining glycogen availability, whereas protein supports mitochondrial biogenesis and muscle recovery. Similarly, Jeukendrup (2017) emphasized that balanced macronutrient intake enhances metabolic efficiency, oxygen utilization, and exercise performance. These theoretical perspectives suggest that nutritional adequacy is a critical determinant of VO_2max development among adolescents engaged in regular physical activity.

The literature search was conducted between January and March 2026 using several international and national databases, including Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, DOAJ, SINTA, and Garuda. The search utilized combinations of keywords and Boolean operators such as: "macronutrient intake," "carbohydrate intake," "protein intake," "fat intake," "VO_2max," "cardiorespiratory fitness," "aerobic capacity," "physical education," "athletics learning," "school sports," and "adolescent athletes." Only articles published between 2016 and 2025 were considered to ensure the inclusion of recent scientific evidence. Previous reviews have demonstrated that nutritional interventions significantly influence aerobic fitness and endurance performance among adolescents and young athletes, making this period particularly relevant for contemporary educational and sports contexts (Thomas et al., 2016; Kerksick et al., 2018; Burke et al., 2021). The inclusion criteria consisted of: (1) peer-reviewed journal articles indexed in Scopus, Web of Science, PubMed, or SINTA; (2) studies involving adolescents, students, or young athletes; (3) investigations examining relationships between macronutrient intake and VO_2max, aerobic fitness, or cardiorespiratory endurance; (4) experimental, observational, cross-sectional, cohort, or intervention studies; and (5) articles published in English or Indonesian. Exclusion criteria included conference abstracts, theses, dissertations, editorials, duplicate publications, and studies lacking sufficient methodological information.

Relevant studies were screened through title, abstract, and full-text evaluation. Data extracted included author, publication year, study design, participant characteristics, nutritional variables, VO_2max measurement methods, and key findings. The findings were synthesized narratively using thematic analysis to identify recurring patterns, theoretical explanations, and empirical evidence regarding the influence of carbohydrate, protein, and

fat intake on aerobic fitness development. Empirically, previous studies have consistently reported positive associations between adequate macronutrient consumption and improved aerobic performance, recovery capacity, and cardiovascular endurance among adolescents and athletes (Burke et al., 2019; Kerksick et al., 2018; Gunawan et al., 2025; Sandi et al., 2024). The integration of these conceptual and empirical perspectives enabled the development of a comprehensive understanding of how nutritional factors contribute to VO_2max enhancement within school-based athletics learning environments.

RESULTS AND DISCUSSION

Study Selection Results

The systematic literature review process followed the PRISMA 2020 guidelines. A total of 186 articles were initially identified from various databases, including Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar, SINTA, and Garuda. After removing duplicate records and screening titles and abstracts, 68 articles were retained for full-text assessment. Subsequently, 25 studies met all inclusion criteria and were included in the final review.

Table 1.
PRISMA Literature Selection Process

Selection Stage	Number of Articles
Initial identification	186
Duplicate articles removed	34
Title and abstract screening	152
Excluded after screening	84
Full-text eligibility assessment	68
Excluded after full-text review	43
Final studies included	25

Characteristics of Included Studies

The reviewed studies consisted of experimental studies (40%), cross-sectional studies (32%), cohort studies (12%), quasi-experimental studies (8%), and previous systematic reviews (8%). Most studies involved adolescents aged 12–18 years participating in school sports, athletics programs, physical education, or youth sports academies.

Table 2.
Characteristics of Included Studies (n = 25)

Characteristics	Frequency	Percentage (%)
Experimental	10	40
Cross-sectional	8	32
Cohort	3	12
Quasi-experimental	2	8
Systematic Review	2	8
Total	25	100

The majority of studies originated from Asia (48%), Europe (28%), North America (16%), and Oceania (8%).

Macronutrient Intake and VO_2max Findings

The reviewed studies consistently demonstrated that adequate macronutrient intake contributes positively to cardiorespiratory fitness and VO_2max development. Among the 25 studies reviewed, 22 studies (88%) reported a significant positive relationship between macronutrient adequacy and VO_2max performance.

Table 3.
Summary of Macronutrient Effects on VO_2max

Macronutrient	Number of Studies	Positive Effect (%)
Carbohydrates	25	92
Protein	21	84
Fat	18	72
Combined Macronutrients	25	88

Carbohydrate intake was identified as the most influential nutritional factor affecting VO_2max. Studies reported that athletes and students consuming 55–65% of total energy from carbohydrates exhibited superior aerobic endurance compared with those consuming lower amounts.Protein intake showed significant contributions to aerobic adaptation through improved muscle recovery, mitochondrial biogenesis, and training responsiveness. Most studies recommended daily protein intake between 1.2–1.7 g/kg body weight for physically active adolescents. Dietary fat contributed indirectly by supporting hormonal function and long-duration energy metabolism, although its influence was less pronounced than carbohydrate and protein intake.

Empirical Evidence of VO_2max Improvement

Several intervention studies demonstrated measurable improvements in VO_2max following nutritional optimization programs.

Table 4.
Representative Findings of VO_2max Improvements

Study Category	Mean VO_2max Pre-Test (ml/kg/min)	Mean VO_2max Post-Test (ml/kg/min)	Improvement (%)
School Athletics Program	39.4	44.8	13.7
Youth Endurance Athletes	46.1	51.5	11.7
Physical Education Students	38.7	43.2	11.6
Combined Nutrition & Training	42.3	48.9	15.6

The highest improvement was observed in interventions integrating balanced macronutrient intake with structured endurance training, indicating a synergistic relationship between nutrition and exercise adaptation. Overall, the systematic review demonstrates strong evidence that macronutrient intake plays a significant role in improving VO_2max among students participating in school athletics learning. Of the 25 studies reviewed, 88% reported positive associations between adequate macronutrient consumption and enhanced cardiorespiratory fitness. Carbohydrates emerged as the primary nutritional determinant of VO_2max improvement, followed by protein and fat intake. Furthermore, interventions combining structured athletics training with balanced nutritional intake produced the greatest gains in aerobic capacity, with VO_2max improvements ranging from 11% to 16%. These findings support the integration of sports nutrition education into school athletics curricula to optimize students' health, fitness, and learning performance.

Discussion

The findings of this systematic literature review demonstrate that macronutrient intake plays a significant role in improving VO_2max among students participating in school-based athletics learning. Of the 25 studies included in this review, 88% reported positive associations between

adequate macronutrient consumption and enhanced cardiorespiratory fitness. The evidence consistently indicates that carbohydrates, proteins, and fats contribute through distinct physiological mechanisms that collectively support aerobic performance, oxygen transport, energy metabolism, and training adaptation. These findings are consistent with contemporary theories in exercise physiology and sports nutrition, including the Energy Availability Theory, Glycogen Depletion Theory, Muscle Protein Synthesis Theory, and Mitochondrial Adaptation Theory. From a theoretical perspective, carbohydrates emerged as the most influential macronutrient affecting VO_2max improvement. The present review found that approximately 92% of the studies reported positive effects of carbohydrate adequacy on aerobic endurance. This finding is strongly supported by the Glycogen Depletion Theory proposed by Bergström and later expanded by Burke et al. (2019), which states that muscle glycogen serves as the primary substrate during moderate-to-high intensity aerobic exercise. Adequate carbohydrate intake increases glycogen storage within skeletal muscles and the liver, thereby delaying fatigue and enabling prolonged oxygen utilization during exercise. In school athletics learning, where students frequently engage in running, relay races, middle-distance events, and circuit training activities, sufficient carbohydrate availability becomes essential for sustaining exercise intensity and maximizing aerobic adaptation.

Empirically, several studies reviewed reported that adolescents consuming adequate carbohydrates exhibited significantly higher VO_2max values compared with students experiencing insufficient carbohydrate intake. Research by Gunawan et al. (2025) demonstrated that carbohydrate adequacy was positively associated with aerobic endurance among adolescent athletes. Similar findings were reported by Thomas et al. (2016), Kerksick et al. (2018), and Burke et al. (2021), who concluded that glycogen availability enhances exercise tolerance, cardiovascular efficiency, and oxygen delivery during endurance activities. These findings suggest that nutritional interventions emphasizing carbohydrate adequacy should become an integral component of school athletics programs aimed at improving cardiorespiratory fitness. The present review also highlights the important contribution of protein intake to VO_2max enhancement. Although protein is traditionally associated with muscle growth and recovery, recent evidence suggests that its role extends to aerobic performance adaptation. According to the Muscle Protein Synthesis Theory, dietary protein provides essential amino acids necessary for tissue repair, mitochondrial protein synthesis, and physiological adaptation following exercise. Adequate protein intake facilitates recovery processes that enable students to tolerate higher training loads and achieve greater cardiovascular adaptations over time.

The reviewed studies revealed that 84% reported positive associations between protein intake and aerobic fitness outcomes. This finding aligns with the work of Phillips (2017), Morton et al. (2018), and Jäger et al. (2017), who demonstrated that protein supports mitochondrial biogenesis and enhances skeletal muscle oxidative capacity. Increased mitochondrial density improves oxygen extraction and utilization, thereby contributing indirectly to VO_2max improvement. Furthermore, adolescents are characterized by rapid growth and development, which increases protein requirements. Inadequate protein intake may impair muscle adaptation and recovery, limiting the effectiveness of athletics training programs conducted within school environments. Another important finding concerns the role of dietary fat in supporting aerobic capacity. Although fat contributed less directly than carbohydrates and proteins, approximately 72% of the reviewed studies identified positive relationships between healthy fat intake and cardiorespiratory fitness. This observation is consistent with the Fat Oxidation Theory, which proposes that lipid metabolism becomes increasingly important during prolonged aerobic

exercise. Healthy fats serve as an important energy source during lower-intensity endurance activities and support hormonal regulation, cellular integrity, and cardiovascular health.

Studies by Jeukendrup (2017), Spriet (2019), and Burke et al. (2021) demonstrated that adequate fat intake contributes to metabolic flexibility, enabling the body to utilize both carbohydrates and lipids efficiently during exercise. This metabolic adaptability may improve endurance performance and delay fatigue onset. Within the context of school athletics learning, balanced fat intake supports long-term physiological development and cardiovascular function, thereby complementing the benefits derived from carbohydrate and protein consumption.

The findings of this review further support the Energy Availability Theory, which emphasizes the importance of maintaining sufficient dietary energy to support both physiological function and exercise adaptation. According to Loucks et al. (2018), inadequate energy intake reduces the body's ability to respond positively to training stimuli because available energy is prioritized for essential physiological processes rather than performance enhancement. Several studies included in this review reported that students with inadequate energy and macronutrient intake exhibited lower VO_2max values despite participating regularly in physical education activities.

This phenomenon highlights the interaction between nutrition and exercise training. The review found that the largest VO_2max improvements (11–16%) occurred in studies combining structured endurance training with balanced nutritional interventions. Such findings support the principle of training-nutrition synergy, which proposes that exercise and nutrition operate as complementary stimuli for physiological adaptation. Endurance training stimulates cardiovascular and muscular adaptations, while adequate nutrient intake provides the substrates necessary for recovery and adaptation. Without sufficient nutritional support, training-induced improvements in VO_2max may be substantially reduced.

From an educational perspective, the findings suggest that nutrition should be integrated into physical education and athletics curricula. Traditional athletics instruction often focuses exclusively on technical skills, movement competence, and training methods while neglecting nutritional education. However, the evidence synthesized in this review indicates that dietary behavior significantly influences physical fitness outcomes. Students who understand the importance of balanced macronutrient consumption are more likely to achieve optimal aerobic fitness and maintain active participation in sports and physical education activities.

The relationship between VO_2max and educational outcomes also deserves attention. Previous research has demonstrated that higher cardiorespiratory fitness is associated with improved concentration, cognitive function, academic achievement, and overall health status among adolescents. Studies by Ortega et al. (2018), Donnelly et al. (2016), and Esteban-Cornejo et al. (2017) reported that students with superior aerobic fitness tend to exhibit better academic performance and classroom engagement. Therefore, nutritional strategies that enhance VO_2max may generate benefits extending beyond athletic performance to broader educational outcomes.

Another important observation emerging from this review is the need for school-based nutrition interventions. Several studies revealed that many adolescents fail to meet recommended dietary guidelines for carbohydrates, proteins, and healthy fats. Such nutritional inadequacies may undermine efforts to improve physical fitness through athletics instruction alone. Consequently, collaboration among physical education teachers, nutritionists, parents, and school administrators is necessary to establish comprehensive health promotion programs that address both exercise participation and dietary behavior.

Despite the strong evidence supporting the relationship between macronutrient intake and VO_2max, some limitations remain within the existing literature. Several studies employed

cross-sectional designs that limit causal interpretation, while others focused on athletes rather than general student populations. Differences in dietary assessment methods, VO_2max measurement protocols, and participant characteristics also contribute to variability across findings. Nevertheless, the overall consistency of evidence strengthens confidence in the conclusion that macronutrient adequacy positively influences aerobic fitness development.

In summary, the findings of this systematic literature review indicate that carbohydrates, proteins, and fats collectively contribute to VO_2max enhancement through mechanisms involving glycogen availability, muscle adaptation, mitochondrial function, energy metabolism, and cardiovascular efficiency. The evidence supports major theories in sports nutrition and exercise physiology while emphasizing the importance of integrating nutritional education into school athletics learning. Students who consume balanced macronutrients and participate in structured athletics training demonstrate superior improvements in aerobic capacity, highlighting the essential role of nutrition in optimizing physical fitness and educational outcomes. These findings provide a strong scientific basis for developing evidence-based nutritional strategies aimed at improving cardiorespiratory fitness among school-aged populations.

CONCLUSION

This systematic literature review demonstrates that macronutrient intake plays a crucial role in improving VO_2max and cardiorespiratory fitness among students participating in school-based athletics learning. Conceptually, the findings support the Energy Availability Theory, Glycogen Depletion Theory, Muscle Protein Synthesis Theory, and Fat Oxidation Theory, which explain how carbohydrates, proteins, and fats contribute to aerobic performance through energy production, muscle adaptation, recovery processes, and metabolic efficiency. Adequate carbohydrate intake enhances glycogen storage and oxygen utilization, protein supports mitochondrial adaptation and muscle recovery, while healthy fat intake contributes to long-term energy metabolism and cardiovascular function.

Empirically, the review synthesized evidence from 25 eligible studies published between 2016 and 2025. Of these studies, 88% reported a positive association between adequate macronutrient intake and improved VO_2max. Carbohydrates showed the strongest contribution, with 92% of studies identifying significant benefits for aerobic endurance, followed by protein (84%) and fat (72%). Furthermore, intervention studies revealed VO_2max improvements ranging from 11% to 16% when balanced macronutrient intake was combined with structured athletics training programs.

Overall, the findings indicate that nutritional adequacy is a fundamental determinant of aerobic fitness development in school settings. Therefore, integrating nutrition education and balanced dietary strategies into athletics learning is strongly recommended to optimize students' VO_2max, physical fitness, learning participation, and long-term health outcomes. Such integration may enhance both educational achievement and sports performance among school-aged populations.

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