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Comprehensive Review of Dietary Supplements Used by Athletes: Types and Benefits

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ABSTRACT

Introduction. A dietary supplement is intended to improve nutrition by providing vitamins, minerals, herbs, or amino acids. These supplements are taken orally, labeled as supplements, and are not meant to be a substitute for regular food. The increasing interest in strength training and fitness emphasizes the significance of proper nutrition. Engaging in physical activity reduces the risk of disease and enhances mental health. More research is required to understand the impact of supplements on performance, health, and the gut microbiome.

Aim of study. The primary objective of this research is to compile existing data on dietary supplements commonly utilized in sports, including but not limited to creatine, protein, branched-chain amino acids, omega-3 fatty acids, and L-citrulline.

Materials and methods. 50 articles pertaining to the issue were subjected to analysis. These articles were sourced from PubMed and Google Scholar, spanning a publication period of 19 years.

Conclusions. Creatine supplementation consistently enhances strength, endurance, and lean mass, particularly when combined with resistance and plyometric training, although its impact on fat mass is modest. Whey protein effectively promotes muscle mass and strength, especially in older adults, and aids in recovery from exercise-induced muscle damage. Branched-Chain Amino Acids can reduce muscle soreness and assist in recovery, but their effects on performance and muscle damage are less pronounced. Omega-3 fatty acids improve muscle recovery and metabolic markers, but exhibit limited synergy with resistance training. L-citrulline elevates arginine levels and improves vascular function, yet its effects on performance are minimal in certain contexts.

KEY WORDS: supplementation, sport, creatine, dietary supplements, protein, BCAA, omega-3 fatty acids, l-citruline

INTRODUCTION

A "dietary supplement" is a product designed to complement the diet by providing additional nutrients, such as vitamins, minerals, herbs, amino acids, or concentrates. These supplements are taken orally, labeled as supplements, and are not intended to replace conventional food. However, they may include substances that were previously marketed as supplements or food before being approved as drugs or biologics, unless declared unlawful. This definition excludes substances approved or investigated as drugs, antibiotics, or biologics, unless they were marketed as supplements before their approval or investigation [4]. In recent years, there

has been a growing interest in strength training and methods aimed at improving physical fitness [1]. A proper diet and nutrition are crucial for achieving a healthy physique and developing an athlete's form [2]. Physical activity is a modifiable factor for cardiovascular diseases. Regular physical activity is associated with a reduced risk of anxiety and depression symptoms, positively influences diabetes management, and helps prevent the development of cancer [5]. Notably, life expectancy is higher among individuals who regularly engage in sports [3]. Individuals who use supplements often seek information about them online. Therefore, it is essential for healthcare professionals to possess the necessary knowledge to ensure the safe use of these products. One study found that acute ingestion of a pre-workout supplement significantly improved anaerobic peak and mean power in recreationally trained males, without adverse effects. However, it did not enhance upper or lower body power or bench press strength, highlighting the need for further research on its effects on anaerobic exercise performance [6]. It is important to consider the impact of various exogenous substances on the microbiota composition. Research by Diego Moreno-Pérez et al. (2018) revealed that protein supplementation affects athletes' microbiomes, specifically reducing the number of Blautia, Roseburia, and Bifidobacterium longum bacteria [7]. Further research is necessary to determine the health consequences of these changes. In this paper, we will focus on gathering available information regarding some supplements used by athletes.

CREATINE

The researchers demonstrated that supplementation with creatine (CR) resulted in a reduction in total calorie intake compared to the placebo group. The CR group exhibited significant improvements in leg press, chest press, overall strength, and leg press endurance, while the placebo group did not experience notable changes. Both groups observed an increase in total body endurance over time, but the creatine group achieved greater progress [8]. CR supplementation, combined with resistance and plyometric training, enhanced lower-limb power in the Abalakov jump test and improved scoring performance in under-16 basketball players [15]. In a study examining the effects of a multi-ingredient performance supplement containing CR and electrolytes, the group that received the supplement showed significant improvements in maximal strength for both the bench press and back squat, as well as during repeated bench press tests to fatigue, compared to the group that received a placebo [16].

A different study revealed that supplementation with CR reduces muscle damage during exercise [9]. CR supplementation results in greater increases in lean tissue mass compared to a placebo [10,11]. In older adults, combining CR supplementation with resistance training has

been shown to potentially double the strength gains achieved through resistance training alone [14].

Scientists conducting a meta-analysis found that in adults under 50, a combination of resistance training and CR supplementation leads to a minor reduction in body fat percentage, without a significant decrease in absolute fat mass [12]. A different meta-analysis revealed that CR supplementation led to an increase in body mass and fat-free mass, while also reducing body fat percentage. Studies that included a maintenance dose of creatine or combined supplementation with resistance training showed even greater effects on body composition [13].

There is evidence suggesting that two years of creatine supplementation, when combined with exercise, could enhance the geometric properties of the bone at the proximal femur [17].

Researchers conducted a study investigating effects of CR supplementation on power output during repeated sprints on a non-motorized treadmill. Following CR supplementation, there was an increase in mean power output and mean running speed during the final 5 seconds of the sprints. Additionally, the reduction in speed across each sprint was mitigated by 16.2% after supplementation. Despite the observed performance improvements, plasma ammonia levels decreased by 20.1% following creatine supplementation [18].

WHEY PROTEIN

Evidence suggests that supplementing with whey protein (WP) effectively increases skeletal muscle mass, muscular strength, and functional capacity in older women, regardless of the timing of supplementation [19]. In a randomized controlled trial participants were given three daily meals designed to meet their specific energy needs. They also did a supervised resistance exercise program for 60 minutes a day, six days a week, for four weeks. The study found that the group that consumed WP experienced greater increases in muscle mass compared to the other group. Additionally, the WP group showed significant improvements in various muscle strength measurements compared to the other group [21].

Researchers examined how consuming WP affects the net protein balance and exercise recovery in trained men. They found that the WP group showed improved net protein balance during overnight recovery and significantly enhanced net protein balance over a 24-hour period, mainly due to reduced protein breakdown. The exercise caused a decrease in repetitions to failure, maximal voluntary contraction strength, peak and mean power, and countermovement jump performance immediately afterward, with all measures showing significant reductions compared to pre-exercise levels. At 10 hours post-exercise, there were

small-to-moderate improvements in recovery of maximal voluntary contraction strength, mean power, and countermovement jump performance in the protein supplementation group. By 24 hours post-exercise, protein supplementation further enhanced maximal voluntary contraction strength, repetitions to failure, and peak power [20].

In a study investigating the effect of WP supplementation on recovery from exercise-induced muscle damage in females, the results showed the following outcomes. Within 72 hours of WP hydrolysate supplementation, flexibility showed improvements beyond baseline levels. The reactive strength index remained higher throughout the recovery period in the WP hydrolysate group. Additionally, creatine kinase levels decreased more significantly 48 hours after exercise-induced muscle damage in those supplemented with WP hydrolysate. These findings suggest that a 4-day WP hydrolysate supplementation is effective in reducing symptoms of exercise-induced muscle damage and enhancing muscle function recovery in physically active women [23].

In a year-long study, researchers investigated the effects of WP supplementation on muscle size, strength, and function in healthy older adults with or without resistance exercise. The study found that WP supplementation alone did not have an impact compared to carbohydrate supplementation. However, when combined with heavy resistance training, WP supplementation significantly increased quadriceps cross-sectional area and both dynamic and isometric knee extensor strength compared to WP alone. On the other hand, light-intensity resistance training with WP supplementation did not lead to an increase in quadriceps cross-sectional area, but it did result in improved dynamic knee extensor strength compared to WP alone [22].

WP supplementation may partially contribute to favorable changes in liver enzymes and a quicker reduction in hepatic fat content in response to resistance exercise [24].

BRANCHED-CHAIN AMINO ACIDS

In a randomized controlled trial, researchers investigated the effect of Branched-Chain Amino Acids (BCAA) supplementation on recovery following acute eccentric exercise. They found that there were no significant differences between the BCAA group and the placebo group over time for creatine kinase levels, soreness, maximum voluntary isometric contraction, vertical jump, or jump squat. However, they did observe that creatine kinase levels were elevated in both groups at 4, 24, 48, and 72 hours after the exercise, but the group that took branched-chain amino acids had lower levels at the 48-hour mark compared to the placebo group. Additionally, both groups experienced an increase in muscle soreness following the

exercise, but participants who took the branched-chain amino acids reported less soreness at 48 and 72 hours. Furthermore, the maximum voluntary isometric contraction strength of individuals who took the supplement returned to normal levels at 24, 48, and 72 hours. However, no significant differences were found between the groups for vertical jump performance or jump squat performance [25].

In resistance-trained males, performance in both the countermovement jump and seated shot-put throw significantly decreased after the strength training session for both the BCAA and placebo groups. However, BCAA supplementation helped reduce the performance decline in both tests compared to the placebo. While muscle soreness increased significantly after the strength training session in both groups, there were no noticeable differences in soreness levels between those who took BCAA and those who took the placebo [29].

After taking a one-time dose of 0.087 grams of branched-chain amino acids per kilogram of body weight, the recovery of isometric strength, countermovement jump height, and perceived muscle soreness improved compared to the placebo. This was observed in resistance-trained athletes with controlled diets after a hypertrophy-focused training session [30].

However, there is evidence that taking BCAA supplements along with carbohydrates did not prevent decreases in lower body strength or improve specific indicators of muscle damage and soreness when compared to taking only carbohydrates during three consecutive days of intense lower-body training [32].

Studies indicate that, compared to a non-caloric placebo, acute supplementation with BCAA can significantly enhance cycling time-trial performance in recreationally active individuals. This improvement was linked to a lower perception of effort during the activity [28].

In a separate study involving older individuals, scientists discovered that those who underwent both exercise and BCAA supplementation showed enhancements in cognitive function and muscle strength, along with elevated albumin levels and reduced TNF-α levels, indicating a decrease in inflammation [26].

Researchers suggest that supplementation with BCAA stimulates the activity of a key protein involved in muscle growth, S6 kinase 1 more than placebo and leucine [31].

Clinical trial conducted on combat sport athletes showed that intake of BCAA improved phase angle values and muscle mass. Athletes who took BCAA also showed increased hemoglobin content in red blood cells and enhanced immune resistance. BCAA intake led to a reduction in interleukin-4 production, suggesting a shift towards a cellular immune response [27].

OMEGA-3 FATTY ACIDS

A study on the effects of Omega-3 polyunsaturated fatty acid (N-3 PUFA) supplementation on exercise-induced muscle damage revealed that participants who took N-3 PUFA supplements experienced significantly lower muscle soreness 24 hours after exercise compared to those who took a placebo. Although Interleukin-6 levels increased in the placebo group following muscle damage and not in the N-3 PUFA group, the differences were not statistically significant. Peak power output decreased significantly in the placebo group compared to pre-exercise levels, while no significant reduction was observed in the N-3 PUFA group 24 hours after muscle damage. However, there were no significant differences in peak power output between the two groups. Maximal voluntary isometric contraction, creatine kinase, and tumor necrosis factor-alpha were all affected by the muscle damage, but there were no discernible differences between the groups for these markers [33].

There is evidence that N-3 PUFA supplementation during endurance training has positive effects on the production of neuroprotective tryptophan metabolites [34].

Supplementing with N-3 PUFAs for three weeks resulted in significant improvements in both metabolic and inflammatory markers in non-elite endurance athletes. The increase in adiponectin and neuregulin-4, along with a reduction in leptin and TNF-α levels, suggests that N-3 PUFAs have a positive impact on both metabolic regulation and inflammatory processes. Additionally, the boost in antioxidant defense highlights the protective role of N-3 PUFAs in managing oxidative stress in endurance athletes [35].

Researchers suggest that older women who take N-3 PUFA supplements in addition to resistance exercise training experience greater gains in muscle mass and type II muscle fiber size compared to those who only do resistance exercise training. However, N-3 PUFA supplementation does not significantly improve strength or muscle protein synthesis. The N-3 PUFA group showed increased activation of anabolic signaling pathways, indicating that N-3 PUFA may promote muscle quality and growth through enhanced anabolic signaling. Nevertheless, further research is required to verify these findings and understand the role of N-3 PUFA in muscle protein synthesis over longer periods of training [38].

On the other hand, data supports that when older adults combine N-3 supplementation with resistance exercise, it increases their isometric muscle strength, even though there are no changes in muscle volume. The improvements in strength seem to be due to better muscle quality rather than increased muscle mass. N-3 doesn't seem to affect the exercise-induced reduction in muscle inflammation and catabolism. This suggests that the main benefits of N-3

supplementation in this context are related to strength gains rather than anti-inflammatory or anticatabolic effects [37].

Researchers discovered that supplementing with DHA-rich n-3 PUFA provided cardiovascular benefits, such as lowering diastolic blood pressure and triglyceride levels, while also enhancing muscle quality in the lower limbs. However, when resistance training and DHA supplementation were combined, no synergistic effects were observed. These findings underscore the independent benefits of both resistance training and DHA supplementation, indicating that their combined use does not yield greater effects than either intervention alone [36].

It has been found that prolonged usage of a nutritional supplement containing N-3 PUFA seems to effectively improve physical function in older adults, even without exercise training and irrespective of changes in lean body mass [39].

L-CITRULLINE

Scientists discovered that supplementing with L-citrulline (L-c) enhances arginine availability, improves splanchnic perfusion, and protects against exercise-induced intestinal stress while maintaining intestinal permeability [40].

Another study shows that taking L-c supplements led to a significant increase in plasma L-arginine levels. Additionally, it reduced the time taken to complete the cycling trial by 1.5% compared to the placebo group. Furthermore, the supplementation improved participants' subjective feelings of reduced muscle fatigue and enhanced concentration immediately after the exercise [49].

Acute L-c supplementation led to increased nitric oxide bioavailability as indicated by higher exhaled nitric oxide levels. However, this did not result in improved respiratory performance or inspiratory muscle oxygenation. This indicates that while L-c may boost nitric oxide production, a single acute dose may not be enough to have a significant impact on respiratory muscle function or oxygenation [41, 42].

However, there is evidence that supplementing with L-c improves arterial vasodilation and muscle oxygenation during exercise by enhancing endothelial function in hypertensive postmenopausal women. These findings suggest that L-c could be a valuable intervention to alleviate the impact of endothelial dysfunction on exercise performance in this population [43].

Another study suggests that L-c supplementation improves endothelial function and, when combined with slow-velocity, low-intensity resistance training, further enhances muscle mass

and strength. This combination presents a promising strategy for addressing both vascular and muscular health in hypertensive postmenopausal women [46].

Whole-body vibration training has been shown to improve leg muscle strength and arterial stiffness. When combined with L-c supplementation, it provided additional benefits by reducing aortic stiffness and enhancing leg lean mass. This combined approach could potentially serve as an intervention to improve cardiovascular health and muscle function in obese postmenopausal women with prehypertension or hypertension, thereby reducing their overall cardiovascular and disability risk [47].

Despite theoretical support for L-c enhancing lactate removal through vasodilation and improved blood flow, the supplement had no observable effect on lactate clearance or exercise recovery, the study supports [44].

Short-term supplementation with L-c improved blood pressure, pulmonary oxygen uptake kinetics, and exercise performance in healthy adults [45].

In a study with nine trained male cyclists, L-c supplementation (6g/day) for 7 days improved time trial performance by 5.2%, but not significantly. It increased average heart rate, perceived exertion, and power output during the time trial, but did not reduce fatigue during the sprint task [48].

Taking single doses of L-citrulline at 3 g or 6 g did not significantly affect heart rate, fatigue, lactate concentration, or perceived exertion in elite soccer players during a short-duration test. Therefore, acute L-citrulline supplementation seems to have minimal impact on performance and recovery in this athletic population [50].

CONCLUSIONS

Creatine supplementation consistently improves physical performance, including strength, endurance, and body composition, compared to a placebo. It also helps reduce muscle damage and enhances recovery, especially when combined with resistance and plyometric training.

Whey protein supplementation significantly boosts muscle mass, strength, and recovery, especially when combined with resistance training. It improves net protein balance, reduces muscle damage, and enhances muscle function in different groups, such as older adults and active women. However, whey protein alone does not impact muscle size without resistance training.

BCAA supplementation can aid in recovery by reducing muscle soreness and improving isometric strength after intense eccentric exercise. It may not significantly impact vertical

jump performance or overall muscle damage, but it can help reduce performance decline in specific tests and improve recovery metrics in resistance-trained individuals.

Omega-3 PUFA supplementation reduces muscle soreness and enhances peak power output following exercise-induced muscle damage. It also improves metabolic and inflammatory markers and promotes muscle quality, offering cardiovascular benefits.

L-citrulline supplementation enhances arginine availability and vascular function, but its effects on exercise performance and recovery may vary. Although it shows promise in reducing muscle fatigue and improving endurance, its impact on specific performance metrics and recovery, particularly in elite athletes, remains limited.

DISCLOSURE

Author's contribution

Adrian Uchto: conceptualization, writing rough preparation

Sara Gierczak: writing rough preparation

Kacper Zając: supervision, resources

Michał Dróżdż: visualization, data curation

Julia Wójcik: methodology, software

Kacper Wojciech Pamuła: check, writing and editing

Karolina Alicja Palacz: investigation, formal analysis

Project administration: Karolina Alicja Palacz

All authors have read and agreed with the published version of the manuscript.

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The authors deny any conflict of interest

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