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**| RESEARCH ARTICLE**

# Are Dietary Supplements, Harmful or Good for Athletes?

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## | ABSTRACT
Athletes are bombarded with nutritional/dietary supplements (NSs/DSs) that promise to improve health, function, and performance. Many of these claims, however, are based on little evidence, and the efficacy and safety of many products are debatable. A review of doping, risk factors, protective factors, performance enhancement, sports performance, dietary supplements, nutritional supplements (NSs), and health consequences was completed using PubMed, Google Scholar, Web of Science, and Science Direct. The inclusion criteria were studies published up until June 2021, which analyzed the content of nutritional/dietary substances and their influence on sports performance. Seventy-three review articles were included in this review. In summary, supplementation will always be a part of athletes' careers due to its perception of ergogenic capabilities, and there is evidence of some dietary nutritional supplements DSs/NSs substances supporting performance enhancement and recovery. However, there is data that due to real harm and unethical manufacturing and marketing practices, some products may contain unwanted/illegal substances. Athletes should be aware of the risk of being tested positive due to contamination of NSs/DSs with a World Anti-Doping Agency (WADA)-banned substance. Athletes and coaches should stick only to supplements that show strong research evidence supporting sports performance and safety use.

## | KEYWORDS

Performance enhancement; dietary supplements; nutritional supplement; doping; health; risk factors.

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## 1. Introduction

According to the Food and Drug Administration (FDA), dietary and nutritional supplements (NSs/DSs) are substances or products that contain essential dietary ingredients intended to enrich the diet. Dietary ingredients which are constituents of these products are vitamins, minerals, herbs or other botanicals, amino acids, enzymes, organ tissues, glandulars, and metabolites. Supplements are meant to augment, not replace, nutrients that are missing from the diet. A nutritional supplement (NS) is a dietary supplement (DS) that is ingested and typically comprises one or more dietary ingredients as expressed above (NCI Dictionary of Cancer Terms - National Cancer Institute, 2021).

In sports, doping is a topic of great interest for all stakeholders, such as amateurs, professionals/elite athletes, sponsors, and viewers who are consumers of the games. While competition is seen as a source of entertainment, a way of life a form of worship for others, it is without a doubt that sport continues to have a major impact on society and the world at large. Hence, the inherent and external motivation to improve performance. Due to marketing claims of performance enhancement in the media, there is increasing use of unregulated DSs among athletes, especially amateurs, which increases the risk of doping and may result in adverse medical events (Mathews, 2018).

While DSs are widely used in the general population, athletes consume them for a variety of reasons. Athletes in a wide range of sporting disciplines may be motivated to increase their performance by ingesting chemicals that alter performance-limiting criteria

(Hardy, 1997), which may result in immediate or long-term damage. Concerns about safety and failed doping tests among athletes due to contamination and the presence of unknown components have followed the rising availability of NSs (Matthews, 2018).

In a recent study conducted in Jamaica, questionnaires were distributed to young athletes aged 12 – 19 years old who were participating in after-school sports training for competitive events. It was found that 57.4% (73/127) of participants who had at least infrequently taken DSs in the previous year had completed significantly more years of training than non-users (3.5 ± 1.5 vs. 2.8 ± 1.2 years), and those training for the Jamaica High School Athletics Championship (Champs) were more likely to take DSs ($P < 0.005$). When compared to other athletes, Champs athletes, particularly males, were more likely to obtain supplements from their coaches and less likely to know the source of the supplements ($P < 0.05$). Supplements were believed to improve sports performance by 37.1 % of respondents. The knowledge segment had poor results, with mean scores of 38%, with Champs participants scoring much worse than athletes competing in other sports. Due to students' lack of understanding of the use of DSs, and the World Anti-Doping Agency (WADA) Code, athletes should be educated about the risks of supplement use (Turfus, 2019).

DSs are becoming more common among athletes, with 50-85% of recreational and 35-100% of competitive athletes reporting use, with the latter using DSs more frequently (Parr, 2017). External substance use, which was once limited to professional athletes, has now become a public health issue, affecting young people and non-competing amateurs in several sporting disciplines.

Doping is an illegal substance or method used in order to increase performance or gain a competitive edge. Sporting disciplines such as athletics, football/soccer, and cycling are known for their popularity and large monetary payload. Anabolic steroids (AAs) are widely used in social settings to enhance physical appearance and performance, and even NSs ostensibly designed to do so frequently include AAs spiked products. While traditional doping substances, including stimulants and drugs, were utilized decades ago, AAs are now more routinely used and can be found in contaminated supplements (Gosetti, 2013).

An educational program such as UK Athletics' Clean Sports program was established to prevent unintentional and intentional doping in junior elite athletes and is successful in reducing participants' likelihood to unintentionally dope in the short and medium-term. The results from a study by Calfee indicate that although the UK Athletics' Clean Sports program decreased short-term intentional doping, continued effectiveness in the long term can only be achieved by strengthening via financial means and building human resource capacity (Calfee, 2006).

The aim of this article is to highlight DSs/NSs use in sports, as well as supplements, use for (i) muscle building, (ii) performance, (iii) recovery/immune response, and to examine views on dietary/nutritional supplementation.

## 2. Methods

### *2.1 Study design*

A search was conducted by the reviewers to identify all the relevant studies on the subject of NSs/DSs and their influence on sports performance from 1997 to 2021. The following steps are included in the methodological outline: (i) documentation of established research objectives and search strategy, (ii) identification and selection of clinical study and peer-reviewed research articles (iii) final selection of clinical and peer-reviewed research articles based on defined eligibility criteria and review objective (iv) arranging and summarizing data and findings from the research articles in various sections and (v) discussing the findings and conclusion.

### *2.2 Literature search strategies*

Electronic databases were searched such as Google Scholar, PubMed, Web of Science, and Science Direct for possibly suitable studies using the key phrases, athletes, doping, risks, protective factors, performance enhancement, NSs/DSs, and health consequences.

### *2.3 Study eligibility criteria - Inclusion and exclusion criteria*

The studies retrieved were prudently examined to omit overlapping data or possible duplication. Those written in other languages were excluded.

The studies included in this review were published from the early 2000s to the present, with only one study from 1997. In addition, the pertinent data that were extracted from published articles by review authors comprised: first author, year of publication, study design, study population size, supplements that are effective in aiding in sports performance, common supplements used by athletes, and possible doping violations due to consumption. There were 268 articles identified through the database, including PubMed, Google Scholar, Web of Science, and Science Direct. We excluded 221 because of duplication and un-relatedness to the topic; 44 articles remained. A second search was conducted, and an additional 35 articles reviewed for inclusion were added. There were 79 eligible articles included in this review (Figure 1).

## 3. Results

### *3.1 Dietary/nutritional supplementation use in sports*

DSs are seen as "foodstuff" or food-like substances. Accordingly, DSs are food components, vitamins, or nonfood substances that are consumed in addition to the regular diet to achieve specific health and/or performance benefit (Maughan, 2018). Other authors have indicated that some athletes consume DSs, which are commercially accessible goods consumed as a complement to a regular diet (Knapik, 2016). DSs have a complex history which makes it difficult to define and characterize due to the fast-growing market and demand for nutraceuticals, which has caused the rapid development of different forms of DSs.

A study conducted in 2017 found that many athletes believe that sports supplement use can improve performance (Hurst, 2017). An earlier study associated the increased consumption of supplementation not only with improving physical performance but also with combating the obesity epidemic (Avelar-Escobar, 2012). A few examples of DSs are sports performance foods (gels, power bars, energy drinks, and protein powders), vitamins and minerals, herbals and botanicals, and ergogenic supplements. Several other categories of DSs exist, and such subcategories appeal to aesthetics/appearance, fat burners/weight loss, and libido enhancement (Garthe, 2018).

Based on the European Parliament Directive, a food supplement is consumed with the aim of complementing a normal diet and other products in simple or combined forms which have been known to possess physiological or nutritious benefits. These products are usually available as pills, capsules, tablets, as well as other related forms such as vials of liquid or powders (Martínez-Sanz, 2017a).

With the increasing availability of DSs on the market, there is increasing use among athletes and the occurrence of unintentional doping. Unintentional doping involves the consumption of unlisted substances in DSs, which has been forbidden by anti-doping regulations and WADA (Martínez-Sanz, 2017a).

Some proposed benefits of DSs by athletes are overall health, increased energy, recovery improvement, and psychological enhancement. Athletes have also acknowledged using DSs to manipulate their body, among other things, such as enhancing training adaptations, as an aid in injury prevention during intense training and the alleviation of musculoskeletal pain (Kerksick, 2018). Some athletic organizations now accept the practical application of approved DSs, with documented evidence of risk-benefit analysis that attests to their effectiveness, safety, and their appropriateness for the athlete's stage of development in their sport (Maughan, 2018).

NSs are used by a large number of persons, athletes, and non-athletes, and unfortunately, some of them contain a number of precursors of AAs along with minerals and vitamins. There are reports that several non-hormonal DSs were discovered to be tainted with AAs that were not labeled. Furthermore, other stimulants, besides naturally occurring analogues of ephedrine, were discovered (Van Thuyne, 2006).

Sportsmen, ranging from amateurs to top athletes, are significant users of NSs. Apart from the potential health hazards linked with the use of NSs, athletes must adhere to the WADA's guidelines, as they are accountable for all chemicals detected in their body fluids, regardless of their source. A study by Kiertscher and DiMarco that comprised 134 players from collegiate universities throughout the USA identified 49 athletes who were at risk for nutritional deficiencies. NSs were used by more at-risk athletes (53.0%) than those who were not (33.0%). Furthermore, there were more athletes (69.0%) who were at risk consumed NSs and were unconcerned about receiving a positive drug test compared with their peers who were concerned (38.0%) about these supplements causing the same result (Kiertscher, 2013).

Athletes are advised to take certain NSs based on the fact that they improve their physical performance during exercise. Other NSs aren't always ergogenic, but they can help athletes train and compete more efficiently by improving their health, adapting to activity, or recovering from injury. There is evidence that creatine monohydrate, omega-3 fatty acids, vitamin D, probiotics, gelatin, and curcumin/tart cherry juice are just a few of the DSs that could support athletes in their training and performing more successfully (Rawson, 2018). Support for sports foods and five evidence-based performance supplements (caffeine, creatine, nitrate/beetroot juice, alanine, and bicarbonate) varies depending on the event, the context, and the goals and responsiveness of the particular athlete (Peeling, 2019).

Some supplements should be consumed before exercise and typically contain a blend of ingredients such as caffeine, creatine, beta-alanine (β-ALA), amino acids, and nitric oxide (NO) agents, which, when combined, can have a synergistic effect on acute exercise performance and later training adaptations when compared to one particular ingredient (Harty, 2018). Supplements should only be taken after an evidence-based examination of their efficacy in enhancing training objectives or competition performance in the athlete's specific event, according to current sports nutrition recommendations (Burke, 2017).

A recent study of 574 Japanese athletic competitors, including 275 juniors (under the age of 20) and 299 seniors, who competed in international championships between 2013 and 2018, showed that NS use was common in 63.9% of the study population. In addition, women, senior athletes, and long-distance runners were much more likely than others to use NSs, according to gender, age, and discipline analyses. Notably, the most frequently used substances were amino acids and vitamins (Tabata, 2020).

High-intensity exercise performed by athletes over the long-term has been associated with suppression of the immune system with a greater risk of illness. This could be due to increased catabolism of tryptophan via the kynurenine pathway, with resulting biosynthesis of a number of neuroactive substances linked to the regulation of immunity and inflammatory responses (Gostner, 2020). Strasser and colleagues examined the effect of probiotic (PRO) supplements on reducing the metabolism of tryptophan and the incidence of urinary tract infections (UTI) in athletes after aerobic exercise. The authors reported reduced breakdown of tryptophan and incidence of UTI after 12 weeks of exercise, although there was a significant improvement in athletic performance (Strasser, 2016).

### *3.2 Supplements for muscle building*

Protein offers needed amino acids for muscle tissue growth, maintenance, and repair. According to findings from a large body of research, protein consumed by athletes increases the response of muscle to training, particularly during exercise and recovery. It is also noted that proteins are consumed by athletes subsequent to exercise where they are optimal in promoting an increase in the effective use of oxygen and muscle growth and development, as well as supporting less protein breakdown within muscles (Radak, 2013).

A recent study comprising 44 active young men was conducted to examine how protein supplementation affected pulmonary $O_2$ uptake at maximum ($VO_2max$) changes during long-term endurance training. After a 10-week period, protein supplementation improved $VO_2max$, fat mass, and lean body mass but did not increase the oxidative capacity of skeletal muscle or performance during endurance training (Knuiman, 2019). Furthermore, another recent study of elderly women examined the effect of L-glutamine supplementation consumed orally on glycemic control, oxidative stress, physical exercise, and the strength of muscles in the knee. Increased oxidative stress parameters such as oxidized and reduced glutathione along with lower D-fructosamine and thiobarbituric acid-reactive substances were found in post-supplementation/physical activity subjects. It was also noted that post-supplementation subjects, besides better glycemic control and improved antioxidant capacity in the blood, had improved power in knee muscles (Amirato, 2021).

Athletes that consume high caloric and protein intakes, protein supplements, protein hydrolysates, and free amino acids may have high L-glutamine levels. A fall in plasma L-glutamine concentration has been linked to prolonged exercise and periods of intensive training, and this has been suggested as a possible reason for exercise-induced immunological dysfunction and increased susceptibility to infection in athletes (Coqueiro, 2019).

Glutamine concentrations in the plasma may be maintained throughout and after extended challenging exercise, and the consumption of glutamine supplementation may not prevent changes in the immune function, as reported in numerous intervention trails pertaining to the use of L-glutamine. Notably, glutamine is requited for the proliferation of lymphocytes, and the rate of the same does not decrease significantly as the amount of blood glutamine concentration remains at a reasonable level post-exercise (Cruzat, 2018).

In healthy adult humans, acute glutamine doses of 20-30 g appear to have no negative effects, and one research in which athletes received 28 g glutamine/day for fourteen days found no harm. Patients tolerated doses of glutamine up to 0.65 g/kg body mass (in solution or as a suspension), and no aberrant plasma ammonia levels were reported (Gleeson, 2008). However, well-controlled scientific investigations in healthy, well-nourished adults have shown no evidence to support the proposed reasons for ingesting glutamine supplements (immune system support, enhanced glycogen synthesis, anti-catabolic effect) (Gleeson, 2008).

Lysine (Lys), a limiting amino acid, is hypothesized to stimulate muscle fiber hypertrophy by boosting protein synthesis. Satellite cells (SCs) play an essential role in the development of skeletal muscle, and there is no evidence of a link between SCs and Lys (Jin, 2019). Furthermore, medium Lys doses controlled SC proliferation in vitro, and the mTORC1 pathway was dramatically boosted. The authors concluded that Lys is not only a chemical building component for protein synthesis but also a signal that activates SCs to modulate muscle growth via the mTORC1 pathway after demonstrating that rapamycin inhibits the mTORC1 pathway and decreases SC proliferation (Jin, 2019).

Some NSs contained branched-chain amino acids (BCAAs), including isoleucine, leucine, and valine. There is not much evidence that BCAAs alone promote protein synthesis in muscles of human subjects, particularly in the post-absorptive. However, there is data that suggests that supplementation with BCAA (before and after exercise) stimulates the synthesis of protein and reduce muscle damage induced by intensive physical exercise in athletes, thus improving performance (Negro, 2008).

Creatine, a popular substance among athletes, is gaining popularity in the medical community. Because skeletal muscle stores over ninety percent of creatine, the impact of creatine supplementation on muscle metabolism has been thoroughly investigated (Buford, 2007). There is evidence that the consumption of creatine as a supplement may result in an increase in skeletal muscle growth and physiology as well as metabolism, although the causal mechanism is yet to be elucidated (Clarke, 2020). Creatine may influence the development of muscles as there is the release of insulin-like growth factors and myostatin, an increased number of myogenic regulatory factors, and subsequent activity of satellite cell mitosis with myofibers formation (Bazgir, 2017). Overall, the mechanisms of action for creatine's effects on muscle mass/growth are still unknown, although current research suggests that it works in a number of means, with similar effects on protein synthesis and myogenesis (Farshidfar, 2017).

Coffee is a regularly consumed beverage around the world, and it is thought to support the prevention of a number of chronic conditions. Nevertheless, its essential mode of action and effect on the differentiation and growth of skeletal muscle is yet to be determined (Samoggia, 2019).

A study was conducted that examined the effect of coffee (0.3% or 1% supplemented in a normal diet) on skeletal muscle growth in mice. There was increased muscle growth and expressions of myosin heavy chains (MHC), including MHC2B, MHC2A, and total MHC in quadricep muscle. There was also elevated insulin growth factor 1 (IGF1) and protein expression of PGC-1, and the activation of the MKK3/6-p38 pathway with a subsequent rise in myogenin expression and the differentiation of myogen. The results of this study suggest that coffee increases the growth and function of skeletal muscle via the modulation of the Akt/mTORC1 signaling pathway (Jang, 2018).

### *3.3 Supplements for performance*

Athletes have tried to boost their performance by consuming an assortment of drugs for as long as competitive sports have existed. This practice has spawned a multibillion-dollar industry that aggressively promotes its products as performance-enhancing, despite the absence of objective, scientific evidence to support such claims.

Caffeine, creatine, and sodium bicarbonate consumption have all been shown to boost multiple-sprint performance (Bishop, 2010). The combination of L-alanine, L-arginine, and *Nigella sativa* improved anaerobic performance and decreased inflammation after strenuous physical activity. More long-term research on trained and untrained subjects is needed to confirm the cumulative/synergic effects of these substances (Hadi, 2021).

A randomized and placebo-controlled study was conducted to examine how supplementing with L-citrulline (Cit), and L-arginine (Arg) influenced biomarkers of NO and other parameters such as exercise performance, $VO_2$ kinetics, and exercise performance. On days six and seven of a seventh-day supplementation regimen with Arg (six gram/day), and Cit (six gram/day), 10 healthy subjects performed cycling exercises with intensity ranging from moderate to severe. It was found that consumption of Cit supplements increased $VO_2$ kinetics, blood pressure, and exercise performance (Bailey, 2015).

Furthermore, Bellinger and Minahan conducted a placebo-controlled, double-blind trial comprising fourteen experienced cyclists ($VO_2$max = 4.5 ± 0.6 Lmin-1) took part. The study involved performing exhausting supramaximal-intensity cycling and a 4- and 10-kilometer time trial. The outcome of beta-alanine (β-ALA) supplementation only or with sprint-interval training (SIT) on training intensity, energy provision, and performance was studied. The authors reported that supramaximal cycling time to exhaustion was enhanced by β-ALA supplementation to a greater extent than placebo (14.9%, 9.2% vs. 9.0%, 6.9%; P = 0.04), although 4- and 10-kilometer time trials were improved to a similar magnitude in both groups. β-ALA enhanced anaerobic capacity (5.5%, 4.2%; P = 0.04) after SIT, although $VO_2$ peak rose similarly in both groups (3.1%, 2.9% vs 3.5%, 2.9%; P 0.05).These findings indicate that β-ALA supplementation enhances training intensity during SIT and affords other benefits to exhaustive supramaximal-intensity supramaximal cycling than only SIT (Bellinger, 2016).

There are a number of studies that have examined the effect of consumption of proteins and carbohydrates (PRO-CHO) on athletic performance parameters, running Time-to-Exhaustion (TTE), and running Time-Trial performance (TT) (Richardson, 2012), (Osterberg, 2008), (Rustad, 2016). A review of 43 trials comprising 326 subjects that consumed CHO-PRO compared with carbohydrates (CHO) only showed increased TT and TTE performances in the former compared with the latter ($P < 0.05$) (Hadi et al., 2021). However, not all studies reported a positive effect of CHO-PRO supplementation on TTE performance (Richardson, 2012), (Osterberg, 2008), and the variabilities could be due to different protocol designs and length of recovery across investigations (Beelen, 2010).

There is inadequate research on the effects of β-ALA supplementation on anaerobic sports performances. Van Thienen and coworkers reported that β-ALA supplementation (2- 4 g per day in 8 weeks) improved sprint peak and mean power following 120 minutes of endurance exercise, thus increasing cyclist performance (Van, 2009). In another study published in the same year by Smith and colleagues, an investigation on the dual effect of β-ALA supplementation (6 g/day) along with high-intensity anaerobic exercise training in 46 randomized, active subjects (over a 6-week period) was conducted. The study found a more significant increase in $VO_2$ peak, lean body mass, time to attain $VO_2$ peak compared with placebo (dextrose), and improved endurance during high-intensity training (Smith, 2009). In another study by Smith and colleagues, β-ALA supplementation delayed neuromuscular fatigue and thus improved high-intensity training in 46 active men following 6 weeks of training (Smith, 2009). However, in a later study that employed a double-blind placebo-controlled protocol with supplementation (6g/day for 5 weeks) of 9 physically active male subjects, there was no advantage for a repeat performance in sprinting compared with the control group (Sweeney, 2010). With such inconsistencies in findings, further research should be carried out to ascertain the effects of supplements on performance outcomes and exercise capacity, as well as the duration of supplementation and strategies for optimal outcomes.

### *3.4 Supplements for recovery/immune response*

A recent randomized controlled research found that supplementing omega-3 polyunsaturated fatty acids (PUFAs) extract with vitamin E and D may improve adipocyte tissue function and mitigate cardiovascular problems in athletes (Żebrowska, 2021). Probiotic therapy improves body composition and cardiorespiratory fitness in long-distance runners while also reducing inflammation (Smarkusz-Zarzecka, 2020). There are reports that amino acid combination decreased cortisol response for the period of exercise without influencing activity-related physiologic markers, particularly glucose or lipid, in healthy, active individuals (Tsuda, 2020).

Specific nutrients can alter immunological function in both health and disease, according to a large body of research (Childs, 2019). During infections, two amino acids, glutamine, and arginine are recognized as "immuno-nutrients." There is clinical evidence to support the fact that these two minerals are dietary "essentiality" for enhancing immune responses in most immunosuppressive situations linked with increased infection rates (Field, 2000). However, more investigations should be carried out to determine the significance of these nutrients in modifying the immunological alterations that occur due to physical exercise in athletes who are healthy (Field, 2000).

Glutamine is an extensively used amino acid in sports nutrition. It has a variety of biological activities, including cell proliferation, energy synthesis, glycogenesis, ammonia buffering, and acid-base balance maintenance, to name a few. There is significant research involving glutamate in sports nutrition in addition to its immune system effects, and there are reports that anti-fatigue is attributed to glutamine. Despite reducing various fatigue parameters, consumption of glutamine supplements may have minimal benefits on performance, given that its ergogenic potential is still unknown (Coqueiro, 2019).

DSs are widely used to improve individual health status, particularly among patients diagnosed with certain diseases, the elderly, and those engaged in sports (Dwyer, 2018). Legal and health dangers associated with DS obtained over the internet are rarely investigated. There is a high prevalence of contamination with dangerous compounds, especially among DS promoted as "natural health products," and potential negative effects are frequently not mentioned (Carlsohn, 2018).

DSs (whey proteins, protein powder, BCAA, caffeine, and creatine) use among 320 adult gym users showed that males used these agents to enhance recovery post-exercise and retain or improve muscle power, strength, and mass (Attlee, 2018). Similar findings were reported in a cross-sectional study of 459 gym members where the DSs (proteins, multivitamins, BCAAs, n-3 fatty acids, carbohydrates) consumed by males were intended for the acceleration of recovery (52.7%), greater muscle mass (55.7%) and performance (47.3%) (Ruano, 2020).

Protein supplements (PSs) are often taken by athletes and physically active persons. A systematic review conducted by Pasiakos and colleagues (2014) and reported that the positive effect of PSs consumed by active health adults following daily physical exercise training includes decreased biomarkers of skeletal muscle damage and muscle soreness, with improved recovery of muscle function and overall physical performance.

An earlier systematic study showed that PSs improved performance recovery and diminished increased biomarkers of skeletal muscle damage in the majority of the studies (60%). Muscle soreness was not significantly affected by PSs, and the authors suggested that more investigation in this area of research is warranted (Poulios, 2019).

Isomaltulose is a disaccharide comprising both fructose and glucose units, and its ability to promote recovery post-exercise has been investigated by researchers (König, 2016). Investigation of the effect of isomaltulose consumption (750 ml. 10% *w/u*) on TT performance during cycling (90 minutes, 20 male athletes) and endurance exercise (EE).

Isomaltulose consumption improved cycling TT performance and EE due to its lower glycemic index, higher blood glucose, and oxidation of fats for the duration of the exercise (König, 2016). Similar results were reported in the study of Japanese triathletes and long-distance athletes after the consumption of isomaltulose beverage (500 ml, 8%) (Hattori, 2019) and soccer players (8% isomaltulose drink during warm-up exercise and halftime), whereas in the latter there was attenuation in the decrease in blood glucose levels at 60 minutes (Stevenson, 2017).

Isomaltulose added to whey protein was found to enhance the recovery benefit of the latter, where there were significant declines in biomarkers of skeletal muscle damage with subsequent enhancement in athletic performance (Kraemer, 2015). Furthermore, Amano and colleagues stated that isomaltulose consumption of beverages (6.5% w/v) and electrolytes might improve rehydration after exercise in physically active, healthy subjects (Amano, 2019). Although the results from these studies suggest that isomaltulose drink may be beneficial to athletes (improved nutrition and physical/cognitive performance), further research is warranted due to diverse findings and insignificant effects in some investigations (Thomas, 2016).

The consumption of creatine monohydrate supplements (0.1 g/kg/day) has been found to improve recovery subsequent to intense physical exercise as there is a decrease in skeletal muscle injury (Kreider,2017). This observation could be due to enhancing activity of creatine kinase, which increases ATP synthesis, and the activation of signaling pathways (e.g., IGF-1), resulting in better recovery and faster repair of skeletal muscle (Bonilla, 2015).

Furthermore, BCAA supplementation appears to decrease damage to skeletal muscle and create an environment for protein synthesis (Kraemer, 2006). These findings are supported by a number of systematic reviews that established that this kind of nutritional supplement (> 200 mg/day/kg) might boost skeletal muscle recovery and alleviate muscle soreness subsequent to high-intensity exercise (Fouré, 2017) (Rahimi, 2017).

## 4. Conclusion

Supplementation will always be a part of athletes' careers due to its perception of ergogenic capabilities; there is evidence of some substances supporting performance enhancement and recovery. However, there is data of real harm due to unethical manufacturing and marketing practices; some products may contain unwanted/illegal substances. Athletes must be aware of the risk of being tested positive due to contamination of DSs/NSs with a WADA-banned substance.

Questions regarding the use of DSs/NSs in healthy athletes should be implemented into the medical history records by physicians. The use of DSs/NSs should be carefully documented. A thorough cost-benefit analysis is recommended, and athletes should consider the risk of being tested positive.

Athletes and coaches must be aware and constantly update themselves on the issues related to the consumption of supplements and should practice great caution when selecting a supplement, properly informing themselves of its effectiveness using evidence-based research and verifying the product's guarantees.

## 5. Limitations

The limitations of this review include the absence of homogeneity among studies. In some of the studies, there was a lack of information on the different types of DSs. The reporting timeframes of dietary supplements were not specific, and this presented some challenges in comparing the findings of studies. Finally, the experimental design and methods were different for athletic populations and did not effectively allow for more precise and comparable data.

## 6. Future studies

Future studies could involve the performance of a meta-analysis that will examine the prevalence of DS by sport and gender, as well as elite in contrast with non-elite athletic status.

**Abbreviations**: DS: dietary supplement, FDA: Food and Drug Administration,
NS: nutritional supplement, WADA: World Anti-Doping Agency, AAs: anabolic steroids, β-ALA: beta-alanine, PRO: probiotic, UTI: urinary tract infections, SCs: satellite cells, BCAAs: branched chain amino acids, MHC: myosin heavy chains, IGF1: insulin growth factor 1, PGC-1: Peroxisome proliferator-activated receptor-γ coactivator-1, MKK3/6-p38: mitogen-activated protein-p-38, Akt/mTORC1: mammalian target of rapamycin/Protein kinase B, Cit: L-citrulline, Arg: L-arginine, NO: nitric oxide, VO2: pulmonary O2 uptake, PRO-CHO: proteins and carbohydrates, TTE: Time-to-Exhaustion, TT: Time-Trial, CHO: carbohydrates (CHO), PRO: proteins, SIT: sprint-interval training, PUFAs: omega-3 polyunsaturated fatty acids, PSs: protein supplements, PED: performance-enhancing drugs, EE: endurance exercise, GI: gastrointestinal, Lys: lysine.

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Figure 1. Stages of study – selection and inclusion of articles.