

Beyond the Hype: A Scientific Assessment of Sports Supplements

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Abstract

The evolving landscape of sports supplements is characterized by their role in enhancing athletic performance through the provision of essential nutrients and compounds often deficient in standard diets. These supplements address specific nutritional needs related to intense physical activity, focusing on energy production, muscle repair, and recovery.

The prevalence of supplement use among athletes ranges from 40% to 100%, influenced by various factors such as competitive level and sport type. Key ingredients, including creatine, beetroot juice, caffeine, protein, and amino acids, are examined for their potential benefits, mechanisms of action, and associated risks. Creatine enhances muscle strength and power, while beetroot juice improves endurance. Caffeine improves cognitive function and athletic performance. Protein and amino acids support muscle growth and recovery. Electrolytes are essential for maintaining hydration and electrolyte balance.

The critical importance of clinical validation is emphasized to ensure the safety, efficacy, and quality of these supplements. Challenges within the market, including lack of scientific evidence for many products and the risk of inadvertent doping due to contamination, are highlighted. Food Safety and Standards Authority of India (FSSAI) and the World Anti-Doping Agency (WADA) play significant roles in overseeing the industry and maintaining lists of prohibited substances. The future of sports supplements is anticipated to embrace a holistic approach, integrating insights from various disciplines and leveraging emerging technologies. Continued research is necessary to establish long-term safety and efficacy profiles, while consumer education remains vital for athletes to prioritize clinically validated supplements that comply with stringent regulatory standards.

Keywords: Sports nutrition; Athletic performance; Ergogenic aids; Protein supplements; Clinical validation; Regulatory oversight

Abbreviations: SS- Sport Supplement; mTOR- Mammalian Target of Rapamycin; 1RM- One-Repetition Maximum; ON- Optimum Nutrition; EAAs- Essential Amino Acids; MPS- Muscle Protein Synthesis; NO- Nitric Oxide; NO₃- Inorganic Nitrate; 5-HT_{2A}- Serotonin Receptor- 2A; BCAA- Branched-Chain Amino Acids IOC and WADA- World Anti- Doping Agency; FSSAI- Food Safety and Standards Authority of India; NCB- Narcotics Control Bureau; SAI- Sports Authority of India; NADA- National Anti Doping Agency; MDMA- Methylenedioxymethamphetamine; THC- Tetrahydrocannabinol; CBD- Cannabidiol, DNP- Dinitrophenol, GMP- Good Manufacturing Practices, ISSN- International Standard Serial Number

Introduction

Sports supplements are dietary products designed to enhance athletic performance by providing essential nutrients and compounds that may be lacking or insufficient in a regular diet. These supplements are often formulated to address specific nutritional needs associated with intense physical activity, such as energy production, muscle repair, and recovery. It looks into the effects of vitamins, minerals, proteins, lipids, and carbs on energy metabolism, muscular performance, and recovery after exercise [1]. The purpose of sports supplement research is to

establish the ideal nutritional intake for athletes based on their body composition, performance objectives, and training regimen. It aims to show how to maintain or improve health status and boost athletic performance through optimal nutritional consumption [2]. Branched-chain amino acids (BCAAs), protein powders, creatine, and pre-workout supplements are common forms of sports supplements.

Prior research has estimated the prevalence of sports supplement utilization among athletes to range between 40% and

100%, with variability attributed to several factors including the competitive level, the specific sport practiced, and the operational definition employed for dietary supplement use [3]. Energy availability and diets high in protein and carbohydrates have been shown to positively improve tissue regeneration and minimize inflammation in injured athletes, it shows how beneficial is sport supplement in athletics [4].

Competitive sports have been governed by tight regulations for the past 50 years or so. All elite athletes are required to always comply with the expanding list of drugs that are prohibited. Nonetheless, gaining a competitive edge is more crucial than ever. Success is essential for the players' personal fulfillment as well as the financial security of their organizations. Naturally, athletes look to supplements in the hopes of discovering vitamins, minerals, or herbs that will give them the extra edge over the competition [5]. Extracted compounds from edible plants may offer potential benefits in preventing stress-related cell damage, oxidative stress, and physiological processes such as metabolism and inflammation [6]. The evolving landscape of lifestyles, dietary preferences, and cultural influences has contributed to a surge in supplement consumption. The rise of vegetarian and vegan diets, the prevalence of additives in food, and the pressures faced by sports stakeholders have all played a role in driving this trend [7].

Athletes will choose to use supplements for a variety of reasons, such as to achieve desired outcomes, including improving power, stamina, training time frame, and injury recovery, as well as to prevent illness and make up for bad food choices [8].

History of Sport Supplements

Ancient writings mention the unique diet of the gladiator school (ad ludum) warriors during the Roman Empire, which included a lot of barley and bell beans among other items. Furthermore, the examination of stable isotopes in collagen-containing bone and teeth samples from gladiators from Journal of Pre-proof archaeological sites led us to the conclusion that the meals were likely supplemented with an assamblea drink to ease discomfort, which changed the Sr/Ca ratio in human tissues [9].

The Olympics were the most significant sporting event in ancient Greece and remain so to this day. Athletes were searching for solutions at the time to enhance performance and reduce

training-related pain. A tailored diet and structured workout regimen were the key components in achieving success. Meat, pork, and fish were substituted for wheat, moist cheese, and dried figs in the diet. They also used poppy-seed-topped white bread [10]. Phenanthrene derivatives found in poppy seeds provide euphoria and lessen pain. Olympic athletes were granted the right of applying "Fuscum Olympionico inscriptum" ointment to alleviate discomfort [11]. Melvin Williams developed a fairly novel conceptualization of ergogenic aids in the context of athletic performance throughout the 1980s. He categorized nutritional, pharmaceutical, physiological, psychological, and mechanical ergogenic aids [12]. In a similar vein, Coyle classified ergogenic aids as performance-related substances such as hypnosis, medications (like coffee), nutrients, and carbohydrates. These tactics aim to delay tiredness and maximize power production [13]. The term "sport supplement" (SS), which was coined in the first half of the 2000s when researchers began recommending that athletes take certain substances as dietary supplements on a regular basis in order to enhance recovery and physical performance. These drugs are administered according to a precise regimen and dosage, which may influence cellular and physiological signaling pathways, optimize training and competition, and repair a deficiency brought on by exercise [14].

Classification of Sports Supplements

Dietary supplements as a sport nutrition which are used in the market are mainly categorized as [15-17]:

Ingredients in Sports Supplements

The common ingredients in the sports supplement include antioxidants (vitamin C, vitamin E, and coenzyme Q10[CoQ10]), arginine, beetroot or beet juice, beta-alanine, betaine, branched-chain amino acids, caffeine, creatine, dehydroepiandrosterone, ginseng, iron, protein, quercetin, and Tribulus terrestris, etc [18].

Creatine:

Creatine monohydrate is a colorless, odorless, crystalline powder that exhibits high water solubility and is commonly marketed as its pure form or in combination with inorganic phosphate compounds, such as creatine phosphate [19]. The most often utilized ergonomic aid for athletes in recent years, creatine supplementation is meant to increase muscle growth and improve performance in sports.

Table 1: Categories of sport nutrition.

Category	Details
Sports foods	It includes sports drinks, bars, gels, ready-to-drink supplements and meal replacement powders. The main goal is when an athlete is pressed for time and prefers to consume less food, using these kinds of products can be especially beneficial in giving protein, carbohydrates, and other nutrients before and/or after exercise to maximize nutrient intake.
Health supplements	It typically contains multivitamins and minerals, fish oils, glucosamine etc. Taken to fulfill dietary requirement after particular, continuous exercise.
Protein and amino acid supplements	This category comprises of proteins like whey, casein, soy, milk proteins, colostrum, etc. Proteins helps in muscle building, increase endurance, and helps to increasing performance in resistance training.
Ergogenic supplements	Any compound having a specific mode of action meant to improve sports performance is considered as ergogenic supplement. Examples include creatine, caffeine, beta-alanine etc. These are the tools that could aid in getting someone ready for exercise, increasing exercise effectiveness, and facilitating recuperation after exercise. Ergogenic aids can also help a person handle strenuous exercise to a larger extent by accelerating their rate of recovery or preventing injuries while they train hard.

Approximately 95% of the body's creatine pool is localized within skeletal muscle, predominantly in the rapidly contracting type II fibers. Of this, two-thirds exists in the phosphorylated form of creatine phosphate, while the remaining one-third is present as free creatine. Creatine functions as a high-energy phosphate compound, providing immediate energy for the contraction of skeletal muscle fibers. The primary objective of creatine supplementation is to elevate both the resting concentrations of creatine phosphate and free creatine within skeletal muscle, with the anticipated outcome of delaying the onset of fatigue during intense physical activity [20]. Given its role as a critical metabolic intermediary, creatine is preferentially distributed to tissues with high energy demands and rapid ATP turnover, including skeletal muscle, the central nervous system, and other metabolically active organs. This endogenous compound is synthesized *de novo* in the kidneys and liver from the amino acids arginine, glycine, and methionine. In addition to endogenous production, creatine can be acquired exogenously through the consumption of meat and various dietary supplements [21].

Majority of team sports often require a balance of aerobic and anaerobic fitness. While aerobic training can improve endurance, it may also lead to strength loss and peripheral fatigue. Creatine supplementation, when judiciously integrated with anaerobic activities in recreational athletes, has been postulated to mitigate the loss of strength associated with aerobic training [22]. According to reports, creatine directly influences the synthesis of muscle protein by modifying certain elements of the mTOR (mammalian target of rapamycin) pathway. By modifying the expressions of myogenic regulatory factors and the secretions of myokines like myostatin and insulin-like growth factor-1, creatine may also have a direct impact on the myogenic process, which is the process by which muscle tissue forms. This could lead to an increase in the mitotic activities of satellite cells and their differentiation into myofiber [23].

Investigations into creatine supplementation have consistently demonstrated enhancements in performance and strength during short-duration, high-intensity exercises. These improvements have been quantified across various metrics, including one-repetition maximum (1RM), muscular power, number of repetitions to failure, muscular endurance, speed, and total force exerted [24,25].

Creatine's osmotic action is known to result in minor water retention and decreased urine volume. Particularly during the loading phase, this could lead to a brief weight gain. Because of the increased intracellular water volume, there is an increased risk of compartment syndrome, muscle cramps, dehydration, or heat illness [26]. Reports of hepatic and renal complications associated with creatine supplementation have emerged in cases where creatine has been combined with other dietary supplements or consumed at dosages significantly exceeding recommended guidelines for extended periods [27]. Some of the available brands of creatine monohydrate are Wellcore Creatine Monohydrate, Optimum Nutrition (ON) Creatine Powder, and MuscleBlaze Creatine Monohydrate etc. which are mainly use as sport supplements.

Beetroot: Beetroot juice has gained significant attention in the sports nutrition world due to its potential to enhance athletic performance [28]. High amounts of inorganic nitrate (NO₃⁻) can be found in beetroot juice, and consuming it has been

shown to raise blood nitric oxide (NO) levels. Numerous studies have found an ergogenic effect of beetroot juice intake on exercise attempts with high oxidative energy metabolism demands, given the actions of NO in increasing vasodilation and blood flow with favorable consequences on muscular contraction [29]. Several studies have found that beetroot juice supplements improve performance in high-intensity exercise modalities where oxidative energy metabolism is the predominant energy metabolism [30,31]. Several clinical trials have investigated the effects of beetroot juice supplementation on athletic performance and key findings from them are improved endurance, improved power output and reduced perceived exertion [29,32,33]. A clinical study involving fourteen moderately trained male master swimmers conducted two incremental swimming tests to investigate the effects of Beetroot Juice Supplementation (BJS). The results demonstrated that BJS positively impacts swimmer performance by reducing the aerobic energy cost and increasing the workload at the anaerobic threshold [30,34]. There isn't a set "standard" amount of beetroot juice to take as a sports supplement, research has generally employed amounts between 140 and 600 ml daily. Side effects of beetroot juice include Gastrointestinal issues, Urine discoloration, and Allergic reactions etc. [35].

Caffeine: Among the most popular and extensively researched sports supplements is caffeine. It's an organic stimulant that can be found in tea, coffee, and some energy drinks [36]. Caffeine, administered at a dosage of 5-10 milligrams per kilogram of body weight, has been demonstrated to significantly enhance glycolytic energy production during high-intensity combat sports activities. This effect is attributed to a combination of increased lactate production and heightened tolerance to elevated blood lactate levels [37]. Caffeine consumption has been shown to confer modest to substantial improvements in several athletic performance parameters, including muscular endurance, movement velocity, muscular strength, sprinting, jumping, and throwing performance, as well as a variety of aerobic and anaerobic sport-specific tasks. While aerobic endurance appears to be the most consistently enhanced exercise modality following caffeine intake, individual responses may vary [38].

Caffeine supplementation in athletes enhances cognitive function by increasing focus and alertness [39]. This effect is mediated by its blockade of adenosine receptors in the brain. Adenosine, a neurotransmitter associated with relaxation and sleep, is inhibited by caffeine, resulting in reduced fatigue and heightened arousal [40,41]. A potential mechanism underlying caffeine's ergogenic effects may involve variations in 5-HT_{2A} receptor activity. These receptors, encoded by the HTR2A gene, modulate dopamine release, which in turn influences alertness, pain perception, and motivation [42].

The optimal timing of caffeine ingestion may be influenced by the specific caffeine source (38). Recent research has focused on the ergogenic potential of low-dose caffeine (~200 mg or ~3 mg/kg body mass) delivered through alternative methods beyond capsules, coffee, and sports drinks, such as chewing gum, bars, gels, mouth rinses, energy drinks, and aerosols [43]. Possible side effect associated with the caffeine are Nerves and Jitters, Insomnia and Gastrointestinal Issues [44,45]. In a 2016 study conducted by Joel D. Stover et al., 14 young adults (18–25 years old) who were engaged in recreational activities took part in a series of running trials. Before each study, participants

were randomized to receive a placebo or a moderate dosage of caffeine (3 mg/kg body weight). The group that took caffeine significantly outperformed the placebo group in terms of running time to exhaustion, according to the results. This implies that young adults' running performance can be improved by coffee [46]. Despite the IOC and WADA's removal of caffeine from the banned substances list in 2004, caffeine remains under WADA surveillance. Athletes are required to maintain urine caffeine concentrations below 12 µg/ml, equivalent to 10 mg/kg body mass ingested orally over an extended period. This threshold significantly exceeds the reported performance-enhancing doses [47].

Protein and amino acid supplements: Protein and amino acid supplements are widely promoted to athletes and physically active individuals as muscle-building and performance-enhancing aids. Similarly, high-protein, low-carbohydrate diets are commonly used for weight loss. However, understanding the nutritional significance and effects of dietary protein and sports supplements varies significantly among athletes and active consumers, particularly in relation to individual exercise intensity, overall dietary intake, and metabolic status [48,49]. Athletes may require elevated protein intake to support optimal protein synthesis, energy production, immune function, and gastrointestinal health during demanding training regimens. Since the intensity and duration of an athletic activity increase the demand for protein, meals before and after the performance as well as on a regular basis throughout the day should contain protein to provide an effective supply of needed. Consuming 20-30 grams of total protein or 10 grams of Essential Amino Acids (EAAs) during or immediately following exercise has been consistently shown to enhance Muscle Protein Synthesis (MPS) and improve nitrogen balance [50].

Branched-chain amino acids (BCAA) including leucine, isoleucine, and valine, are vital amino acids that have attracted a lot of interest in the field of sports nutrition [51]. Skeletal muscle is the main organ where BCAAs are digested. Here, they are used as a fuel source and are essential for both muscle repair and protein synthesis [52]. Leucine, a specific BCAA, is known to play a key role in regulating protein production through the mTOR pathway [53].

Existing research suggests that Branched-Chain Amino Acid (BCAA) supplementation may enhance athletic performance by reducing muscle soreness, promoting muscle protein synthesis, and delaying fatigue. These effects are believed to be mediated by BCAA's ability to stimulate protein anabolism and inhibit muscle protein catabolism [54]. A 2021 case study by Radloff et al. examined the impact of BCAA supplementation on the running kinematics of an ultra-endurance athlete. Employing a cyclical supplementation protocol, the runner consumed a BCAA beverage during some training sessions and a placebo during others. The findings revealed a significant reduction in vertical oscillation during running when BCAA supplementation was used, suggesting improved running economy, characterized by a decrease in metabolic cost per unit distance [55]. A meta-analysis investigating the effects of Branched-Chain Amino Acid (BCAA) supplementation on exercise-induced muscle damage biomarkers and muscle soreness revealed a significant reduction in Creatine Kinase (CK) levels at the immediate and 72-hour post-exercise time points. Furthermore, BCAA supplementation was associated with a marked attenuation of Delayed-Onset Muscle Soreness

(DOMS) from 24 to 96 hours post-exercise [56]. Well-liked BCAA supplements are usually flavored to enhance flavor and are available in powder form. BCAA supplements that are sold commercially include Xtend, Scivation XPC, and Optimum Nutrition Amino Energy.

Carbohydrate electrolyte solutions as a sports drink

Energy drinks, often marketed as sports drinks, are beverages containing sugar and various ingredients designed to enhance physical and mental performance [57]. Water balance is crucial for exercise performance, and functional beverages offer a convenient way to hydrate, replenish electrolytes, and provide necessary nutrients consumed or depleted during physical activity and competitive events [58]. These drinks are formulated to increase energy, improve focus, and potentially prevent bone and joint pain [59]. Many energy drinks contain optimal levels of carbohydrates and electrolytes to aid in glycogen replenishment and hydration [57].

During physical activity, electrolytes play a pivotal role in various biological functions. Sodium and potassium are particularly important for regulating body water balance and maintaining muscle excitability, cellular permeability, and protein and carbohydrate synthesis. Chloride is essential for maintaining osmotic pressure, acid-base balance, and gastric function [60]. Given the potential association between salt loss and muscle cramps, it is crucial to identify athletes susceptible to muscle cramps due to excessive electrolyte depletion during exercise [61]. The dietary supplementation of functional lipid-enriched beverages has become a widespread practice in sports nutrition [62].

Strengthened Regulatory Oversight of Sports Supplements

To strengthen sports supplement regulations in India, the Food Safety and Standards Authority of India (FSSAI) has finalized anti-doping guidelines in collaboration with Representatives from India's Narcotics Control Bureau (NCB), NADA, and the Sports Authority of India (SAI). These guidelines aim to ensure that over-the-counter sports nutrition products sold in India do not contain prohibited performance-enhancing substances. Manufacturers and retailers, both online and offline, will be subject to increased regulatory oversight. Sports supplement manufacturers are now required to register with or obtain a license from the FSSAI and adhere to specific labeling requirements. Products must be labeled as "intended for sports persons", carry disclaimers regarding "not recommended for infants / children", and declare that they do not contain any substances prohibited by the World Anti-Doping Agency (WADA) [66-68].

Banned sport Supplement: A rising number of athletes are using dietary supplements every year. Inadvertent doping happens because of the high usage rates. Positive anti-doping test results resulting from the use of any supplement containing unlisted drugs prohibited by anti-doping laws and organizations, such as the World Anti-Doping Agency (WADA), are referred to as unintentional doping [63]. It has been claimed that some athletes tested positive for doping as a result of using nutritional supplements that either had contaminated products or had inadequate labeling [64].

According to WADA the substances which are banned from sport supplement are:

- 1) Anabolic Agents: Synthetic testosterone derivatives known as anabolic steroids are prohibited because they have the ability to boost muscle growth, reduce protein breakdown, and promote protein synthesis by activating the androgen receptor.
- 2) Peptide Hormones and Growth Factors: It contains Erythropoietin, Chorionic Gonadotrophin and Luteinizing Hormone, and growth factors.
- 3) β 2 Agonists: e.g., Terbutaline.
- 4) Diuretics and Masking Agents: The purpose of masking agents is to obstruct markers or other chemicals on the Prohibited List from being analytically tested. Diuretics are believed to dilute and obstruct the detection of prohibited compounds in urine because they increase the production of urine.
- 5) Stimulant: It includes substances of abuse such as cocaine and methylenedioxymethamphetamine (MDMA / "ecstasy"). All stimulants, including all optical isomers, e.g., d- and l- where relevant, are prohibited at all times.
- 6) Canabinoids: In accordance with relevant regulations, all naturally occurring and synthetically derived cannabinoids are subject to prohibition. This encompasses cannabinoids present in *Cannabis sativa* L. (cannabis, hashish, marijuana), synthetic cannabinoids that replicate the effects of Δ^9 -Tetrahydrocannabinol (THC), and all forms of THC itself. However, Cannabidiol (CBD) is exempt from this prohibition.
- 7) Glucocorticoids: All glucocorticoids are prohibited when administered by any injectable, oral [including oromucosal (e.g. buccal, gingival, sublingual)] or rectal route.
- 8) Unapproved substances: This class covers many different substances including but not limited to BPC-157, 2,4-Dinitrophenol (DNP) and Troponin Activators (e.g., Reldesemtiv and Tirasemtiv) [65,66].

Clinical Validation

To guarantee the safety, effectiveness, and quality of sports nutrition supplements, clinical validation is essential. Clinically certified supplements are free of hazardous ingredients and adhere to anti-doping laws. They have been put through extensive testing and research to demonstrate their efficacy in improving sports performance and recovery [2].

The possibility for adverse consequences is one of the main issues with sports supplements. A meta-epidemiological analysis of case reports of unfavorable events connected to sports nutrition supplements discovered that crucial details, like prior medical history and consistent prescription medication use, were frequently absent from assessments of causality. An alternate explanation for the unfavorable event was not provided in 23% of the cases. This emphasizes how crucial it is to do extensive safety testing and disclose any possible contraindications [68].

Before using sports supplements, it's vital to be aware of their possible adverse effects and contraindications. Unlisted substances in many supplements can include stimulants and anabolic steroids, which can lead to hazards like hormonal imbalances and worsening cardiovascular problems [69]. Due to unclear labeling, supplements that include androgenic steroids run the risk of causing androgen shortage and symptoms such as hypogonadism. Elevated blood urea and creatinine levels from high protein and creatine supplementation may result in renal injury [70]. Increased anxiety, agitation, psychotic episodes, and skin-related adverse effects including acne and hair loss have all been linked to the use of specific supplements, particularly those that include anabolic steroids [71]. Numer-

ous supplements have the potential to negatively interact with drugs. Common side effects of pre-workout supplements include headaches, sleeplessness, water retention, upset stomach, and elevated heart rate in sensitive people. Even while some supplements might improve performance in the short term, it's frequently unknown if they're safe over the long run.

The ISSN assessment pointed out that classifications can alter in the future as new data becomes available, suggesting that many supplements' long-term effects have not been sufficiently investigated. Possible adverse consequences, as those detailed in the meta-epidemiological study, highlight the necessity of thorough long-term safety evaluation [67].

There is insufficient scientific proof for many sports supplements to back up their advertised benefits. The ISSN reviewed supplements and ranked them according to the level and quantity of available scientific evidence. There are only few supplements that fall into the "Strong Evidence to Support Efficacy and Apparently Safe" category, such creatine monohydrate and beta-alanine. Most supplements have little to no data supporting their safety and/or efficacy, or there was evidence but it was inconsistent.

The sports supplement market is flooded with countless products, many of which make exaggerated claims or lack scientific validation. Consumer education along with effective differentiating brand positioning can greatly increase a brand's attractiveness in a crowded market. In order to attract health-conscious customers looking for specialized nutritional solutions, businesses must strategically differentiate their products as the worldwide sports nutrition market grows and is expected to reach over \$78.3 billion by 2032. In the current market, brands that place a higher priority on clinical validation can stand out due to the lack of regulations and the prevalence of unvalidated supplements. Supplements that have undergone clinical validation have a higher probability of meeting regulatory requirements and guidelines, being produced in facilities that follow Good Manufacturing Practices (GMP) and being subjected to independent testing. Brands may gain consumer trust and establish themselves as industry leaders in sports nutrition by highlighting these factors and being open and honest about their product formulations and research.

Manufacturers and sellers often promote their products by claiming they improve strength, endurance, exercise efficiency, and tolerance for intense training. These assertions aren't always backed up by data, though. It is essential that consumers get education regarding the significance of selecting clinically verified supplements and the possible hazards linked to unvalidated products. Many fitness enthusiasts and sportsmen are not well-versed on the advantages and proper use of supplements. Companies can close this information gap by making their product details easily readable, including thorough descriptions of the components and their medicinal uses. To sum up, clinical validation is necessary to guarantee the safety, efficacy, and quality of sports supplements. Customers should favor supplements that have undergone extensive testing and study and stay clear of unvalidated goods.

The Future of Sports Supplements

The medical field of sports supplement studies the connection between exercise performance and dietary intake. The evolution of sports supplements as performance-enhancing aids has

mirrored the growth of sports competition as a social phenomenon. Beyond the scope of doping regulations, SS have been strategically employed to optimize the modifiable pillars of performance: health, training, and competition [72]. Given the interconnectedness of sports supplement and sports science, a more holistic approach is warranted, encompassing contributions from diverse disciplines, stakeholders, sponsors, and industry representatives. Recent advancements in physiology, sports supplements, and technology have facilitated the integration of these elements into innovative strategies for enhancing sport performance. The convergence of emerging technologies presents exciting prospects for ground breaking research in sports supplements. By embracing real-world settings, practical solutions, and a holistic perspective, sports nutrition research can make significant strides in the near future.

Conclusion

Sports supplements have become an integral part of the modern athlete's regimen, offering potential benefits in enhancing performance, recovery, and overall well-being. By understanding the diverse range of sports supplements and their mechanisms of action, athletes can make informed decisions about incorporating these products into their training regimens. Sports supplements offer potential benefits in enhancing athletic performance by addressing specific nutritional needs. Key ingredients like creatine, beetroot juice, caffeine, protein, and amino acids play crucial roles in improving muscle strength, endurance, cognitive function, and recovery. The FSSAI has finalized anti-doping guidelines to strengthen sports supplement regulations in India. These guidelines aim to prevent the presence of prohibited substances in over-the-counter sports nutrition products. Manufacturers and retailers are now subject to increased oversight, requiring registration or licensing with the FSSAI and adherence to specific labeling requirements, including disclaimers regarding prohibited substances. Clinical validation is crucial for ensuring the safety, efficacy, and quality of sports supplements. Consumers should prioritize clinically validated products and be aware of potential adverse effects associated with unvalidated supplements. Manufacturers should invest in clinical research to substantiate their claims and differentiate their brands in the competitive market.

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