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PROFILE OF SCIENTIFIC PRODUCTION ON CREATINE SUPPLEMENTATION IN THE WEB OF SCIENCE INDEX DATABASE (1950-2024)

Marcelo Augusto Alves de Oliveira[1], Jonatas Deivyson Reis da Silva Duarte[2,3,4]
Michelle Jalousie Kommers[2,5], Carlos Alexandre Fett [2,3,4], Waléria Christiane Rezende Fett[1,2]

ABSTRACT

Introduction: Creatine supplementation is one of the most studied ergogenic substances with proven efficacy in high-intensity intermittent exercise and strength training. Objective: To conduct a bibliometric analysis to identify the most researched topics, the most cited articles, the journals, countries and researchers with the most scientific production on creatine supplementation, in the Web of Science indexing database. Materials and Methods: The keyword “creatine supplementation” was used to search for articles published on this topic in the title, abstract and/or keywords. Data collection was carried out on December 31, 2024. Results: Scientific production on creatine supplementation has seen remarkable growth since the early 1990s, with an exponential increase in the 21st century. The University of São Paulo (USP) in Brazil (n = 178) leads in the number of institutional publications, while the United States (n = 1,364) is the most productive country. The journal Nutrients (n = 226) is the journal with the highest number of published articles, and Darren Candow (n = 70) stands out as the most prolific researcher. The area of Sports Sciences (n = 1,359) concentrates the greatest volume of research. Conclusion: Most of the scientific production on creatine supplementation is focused on improving sports performance. The subject is of global interest, with significant contributions from different countries and researchers.

Key words: Sports nutrition. Physical education. Physical exercise.

1 - Faculdade de Educação Física. Universidade Federal de Mato Grosso, Cuiabá, Brasil.
2 - Time de Investigação Metabólica, Esporte e Saúde, Universidade Federal de Mato Grosso, Cuiabá, Brasil.
3 - Laboratório de Análise Esportiva, Universidade Federal de Mato Grosso, Cuiabá, Brasil.

RESUMO

Perfil da produção científica sobre suplementação de creatina na base de dados index Web of Science (1950-2024)

Introdução**:** A suplementação de creatina é uma das substâncias ergogênicas mais estudadas com eficácia comprovada em exercícios intermitentes de alta intensidade e no treinamento de força. Objetivo**:** Conduzir uma análise bibliométrica para identificar os temas mais investigados, os artigos mais citados, os periódicos, países e pesquisadores com maior produção científica sobre suplementação de creatina, na base de indexação Web of Science. Materiais e Métodos**:** A palavra-chave "creatine supplementation" foi utilizada para buscar artigos publicados com esse tema no título, resumo e/ou palavras-chave. A coleta de dados foi realizada em 31 de dezembro de 2024. Resultados**:** A produção científica sobre suplementação de creatina teve um crescimento notável a partir do início da década de 1990, com um aumento exponencial no século XXI. A Universidade de São Paulo (USP), no Brasil (n = 178), lidera em número de publicações institucionais, enquanto os Estados Unidos (n = 1.364) é o país mais produtivo. A revista Nutrients (n = 226) é o periódico com maior número de artigos publicados, e Darren Candow (n = 70) destaca-se como o pesquisador mais prolífico. A área de Ciências do Esporte (n = 1.359) concentra o maior volume de investigações. Conclusão**:** A maior parte da produção científica sobre suplementação de creatina está voltada para a melhoria do desempenho esportivo. O tema desperta interesse global, com contribuições significativas de diferentes países e pesquisadores.

Palavras-chave: Nutrição esportiva. Educação física. Exercício físico.

4 - Programa de Pós-graduação em Ciências da Saúde pela Faculdade de Medicina, Universidade Federal de Mato Grosso, Cuiabá, Brasil.

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INTRODUCTION

Creatine is a widely popular and globally consumed supplement that plays a vital role in energy metabolism, particularly in muscle cells and the brain (Hall et al., 2021).

It is a natural organic compound produced endogenously in the body and obtained through diet, milk, white meat, fish, molluscs, crustaceans, especially red meat (Wuertz, Reiser, 2023).

In the body it is synthesized mainly in the liver and kidneys, with a minor contribution from the pancreas, from the amino acids arginine, glycine and methionine, amounting to an average production of 1 gram per day (Arazi et al., 2021; Salles Painelli et al., 2014).

It is estimated that the daily creatine requirement for a 70 kg man is 2 g/day and that up to half can be obtained from a typical omnivorous diet, with the remaining amount being produced by the body (Bonilla et al., 2024).

When supplemented with exogenous creatine, intramuscular and brain stores of creatine and its phosphorylated form (phosphocreatine (PCr) increase, playing a fundamental role in the energy metabolism of skeletal muscle, mainly through its involvement in the ATP-CP (adenosine triphosphate - creatine phosphate) system, also known as the phosphagen system (Forbes et al., 2023).

This system is characterized by a one-step chemical reaction catalyzed by creatine kinase (CK), where creatine phosphate (CP) is converted into creatine and inorganic phosphate (Pi) (Santacruz et al., 2017). Pi then rephosphorylates adenosine diphosphate (ADP) to regenerate ATP, providing an immediate source of energy for muscle contractions during high-intensity activities (Campos et al., 2012).

The ATP-CP system is notably the least complex of the body's three main energy-producing systems, which allows for faster ATP production, albeit with a lower energy yield per unit of substrate. Each molecule of CP can generate one molecule of ATP, producing an energy production ratio of 1:1 (Varillas-Delgado, 2024).

As exercise begins or intensity increases, ATP levels in the muscle decrease while ADP levels increase, signaling the need for energy replacement. This increase in ADP stimulates CK activity, accelerating the ATP-CP reaction and increasing ATP regeneration (Varillas-Delgado, 2024).

Creatine accumulation leads to cellular hyperhydration, which acts as an anabolic signal, promoting muscle protein synthesis and potentially decreasing protein degradation (Forbes et al., 2023).

The Akt/mTOR signaling pathway also plays a crucial role in mediating the effects of creatine on muscle hypertrophy and performance. This pathway integrates various signals from growth factors, nutrients and mechanical stimuli to regulate protein synthesis and muscle adaptations. Activation of the Akt/mTOR pathway triggers downstream effects that increase protein translation initiation and ribosomal biogenesis, further supporting muscle hypertrophy (Wu et al., 2022).

These mechanisms provide greater energy availability for both the muscles and the brain (Sandkühler et al., 2023), resulting in improved performance in intense, short-duration activities with intermittent efforts (Forbes et al., 2023), as well as enhancing the development of muscle strength in resistance training (Bonilla et al., 2021), typical of anaerobic exercise. Around 95% of the body's creatine is stored in fast twitch skeletal muscle, also known as type II fibers (Butts et al., 2018).

On the other hand, creatine's ergogenic benefits appear to be limited or non-existent in endurance activities (Fernández-Landa et al., 2023).

Creatine is widely recognized as a safe supplement, offering various health benefits, including anti-inflammatory effects, immunomodulators, improvements in cognitive function, neuroprotective properties, aid in glycemic control, as well as contributing to the optimization of metabolism and the promotion of cardiovascular health, among others (Kreider, Stout, 2021).

Its use is recommended for different age groups, and it can be safely consumed by children and adolescents (Jagim, Kerksick, 2021), adults (Wax et al., 2021) and the elderly (Forbes, Candow, 2024).

As creatine is the most studied supplement in the world (Kreider et al., 2017), there is no bibliometric analysis based on the topic.

Thus, bibliometric review is a fundamental approach to filling this gap by providing a quantitative assessment aimed at identifying, mapping and evaluating the

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scientific production associated with a specific topic (Zupic, Čater, 2015).

Bibliometric methodology uses metrics such as the number of publications, citations, keywords and the identification of the most productive countries, researchers and institutions (Donthu et al., 2021).

It offers a comprehensive view of the state of the art, helps detect gaps in the literature and guides new directions for future research (Donthu et al., 2021).

In addition, it can help in choosing journals to submit articles to and in identifying relevant universities and researchers for academic partnerships and graduate programs.

Based on this framework, this study aims to carry out a bibliometric analysis of publications related to creatine supplementation indexed in the Web of Science database.

The research will be based on the following criteria: (a) the most explored areas of knowledge; (b) the journals with the highest volume of publications; (c) the most cited articles; and (d) the researchers, universities and countries with the highest scientific production on the subje**ct.**

MATERIALS AND METHODS

The search for the keyword “creatine supplementation” in the title, abstract and/or keyword of the articles was carried out on the Web of Science indexing database on December 31, 2024.

No minimum search time was set. The Web of Science is recognized as an excellent platform for bibliometric analysis (Reis et al., 2022), offering a comprehensive multidisciplinary collection (Martín-Martín et al., 2018).

During the consultation, the platform provided detailed information on the years of publication, authors, journals, areas of knowledge, universities, among other relevant data related to the search term.

RESULTS

Four thousand six hundred and eighty articles were identified, totaling 143,105 citations. The first recorded article was published in 1950, entitled Studies on the Enlarged Hock Disorder (Perosis) in Turkeys: Three Figures (Scott, 1950).

The year with the highest number of publications was 2021, with 306 articles. From 1994 onwards, there was an increase in the number of publications, which became more significant in the 21st century (Figure 1).

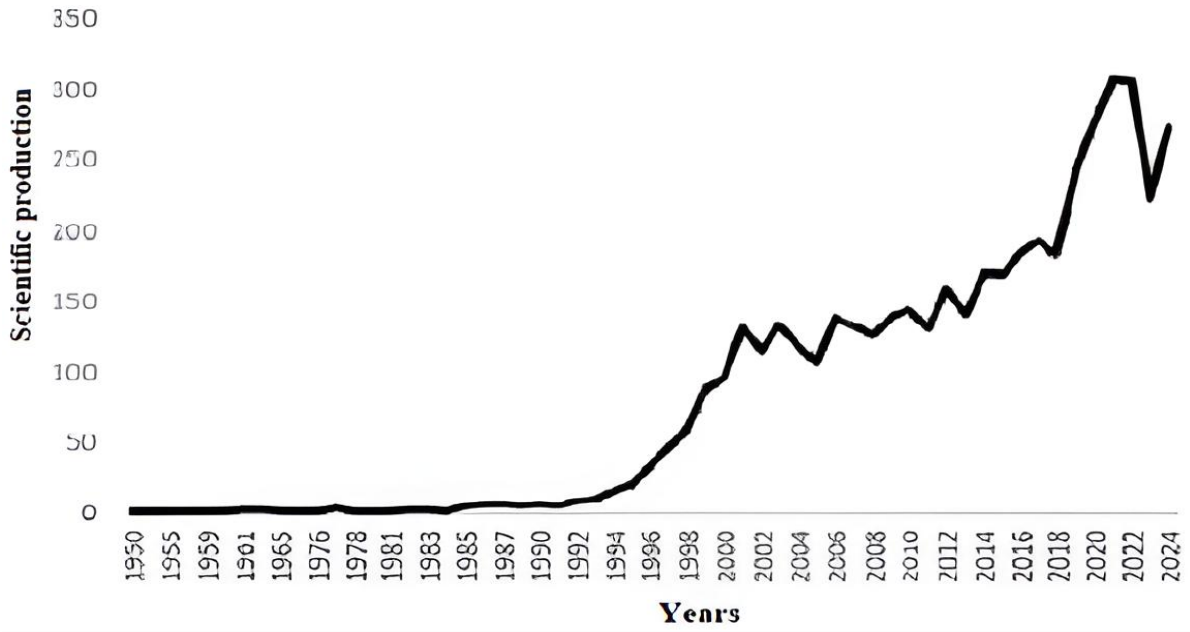

Figure 1 - Scientific production on creatine supplementation in different years.

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Table 1 shows the most productive universities in creatine supplementation research. University of São Paulo, in Brazil, leads the ranking with 178 publications, followed by the Florida State University System, in the United States, with 100 publications. Seven North American universities are among the ten institutions that produce the most research in this area. Figure 2 shows the ten countries with the highest scientific output related to creatine supplementation, highlighting the United States as the largest producer of studies, followed by Brazil and China in third place.

Table 1 - Top ten most productive universities in relation to creatine

Institution	nº of articles
University of São Paulo (Brazil)	178
State University System of Florida (USA)	100
McMaster University (Canada)	95
University of Regina (Canada)	87
Texas A M University System (USA)	82
University of Texas System (USA)	80
University of North Carolina (USA)	64
University of California System (USA)	59
Harvard University (USA)	57
University System os Ohio (USA)	57

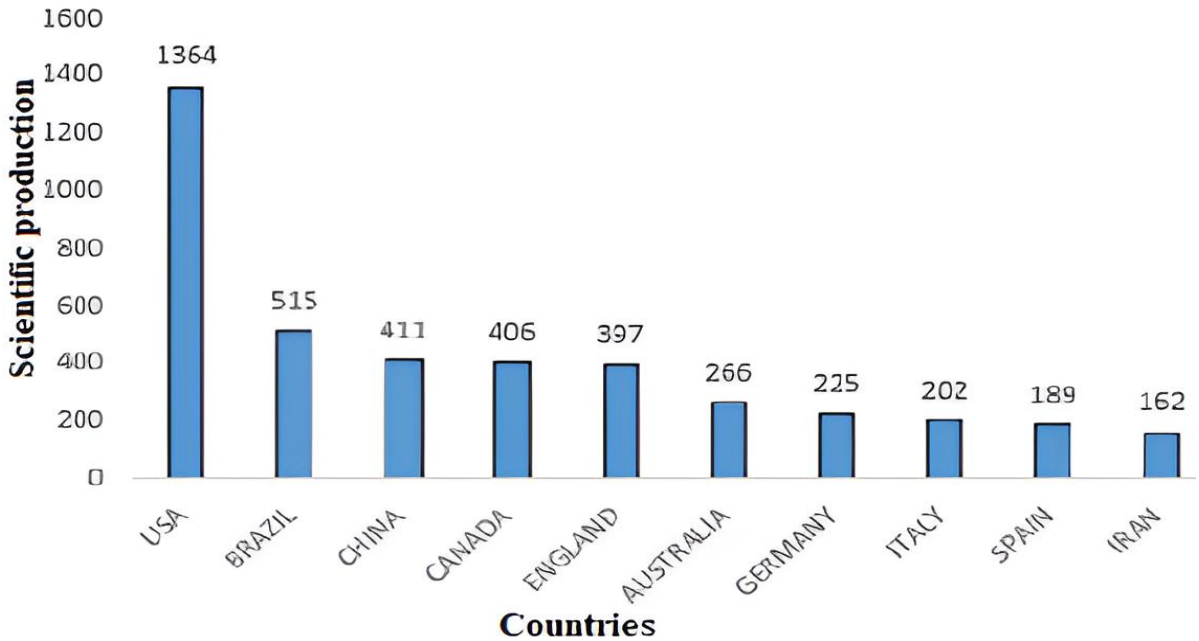

Figure 2 - Distribution of scientific publications on creatine supplementation by country.

Table 2 shows the ten main areas of knowledge related to research into creatine supplementation, highlighting the breadth of their academic and scientific impact. The area with the highest number of publications is Sports Sciences, with a significant total of 1,359 articles, reflecting the continued interest in the use of creatine to improve physical performance and recovery in athletes. Next, Nutrition and Dietetics ranks second with 998 publications, highlighting the fundamental role of creatine as a widely studied nutritional supplement to optimize diet and contribute to muscle health.

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Table 2 - publications of articles with creatine in different areas of knowledge.

Areas of knowledge	nº of articles
Sport Sciences	1,359
Nutrition Dietetics	998
Physiology	468
Biochemistry Molecular Biology	389
Agriculture Dairy Animal Science	305
Neurosciences	229
Pharmacology Pharmacy	221
Veterinary Sciences	219
Endocrinology Metabolism	189

The third most representative area is Physiology, with 468 studies, highlighting the importance of this substance in the biochemical and physiological processes of the human body.

No que se refere às revistas científicas que mais publicam artigos sobre suplementação de creatina na base de indexação Web of Science, a revista suíça Nutrients destaca-se como a mais produtiva, com um total de 226 publicações. Entre as dez revistas com maior número de artigos sobre o tema, as revistas norte-americanas dominam o ranking, representando metade das posições (n = 5), conforme apresentado na Tabela 3. Esses dados reforçam o protagonismo das revistas dos Estados Unidos na disseminação de pesquisas relacionadas à creatina.

Table 3 - Journals that published the most articles on creatine.

ISSN	Journal	nº of articles
2072-6643	Nutrients (Switzerland)	226
0195-9131	Medice and Science in Sports and Exercise (USA)	189
1533-4287	Journal of Strength & Conditioning Research (USA)	141
1550-2783	Journal of the International Society of Sports Nutrition (USA)	137
1543-2742	International journal of sport nutrition and exercise metabolism (USA)	99
1438-2199	Amino acids Austria)	80
1439-6319	European Journal of Applied Physiology (Germany)	66
1522-1601	Journal of Applied Physiology (USA)	59
1525-3171	Poultry Science (United Kingdom)	53
1827-1928	Journal of Sports Medicine and Physical Fitness (Italy)	53

Among the ten most cited articles on creatine supplementation, the study entitled “Arginine metabolism and nutrition in growth, health and disease” (Wu et al., 2009) ranks first, with 980 citations, reflecting its influence and relevance in the area of nutritional and metabolic research. The second most cited article, with 955 citations, is “Establishment and identification of small cell lung cancer cell lines having classic and variant features” (Carney et al., 1985), demonstrating the breadth of scientific applications involving creatine supplementation in different study contexts. Table 4 provides a detailed overview of the ten most cited articles, highlighting their contributions to the advancement of knowledge and their impact on global scientific literature.

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Table 4 - Top - 10 of the most cited article.

Reference	Title	Authors	Year	nº of citations
Wu et al., (2009)	Arginine metabolism and nutrition in growth, health and disease	Guoyao Wu; Fuller W. Bazer; Teresa A. Davis; Sung Woo Kim; Peng Li, J. Marc Rhoads; M. Carey Satterfield; Stephen B. Smith; Thomas E. Spencer; Yulong Yin	2009	980
Carney et al., (1985)	Establishment and identification of small cell lung cancer cell lines having classic and variant features	Desmond N. Carney; Adi F. Gazdar; Gerold Bepler; John G. Guccion; Paul J. Marangos; Terry W. Moody; Mark H. Zweig; John D. Minna	1985	955
Harris et al., (1992)	Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation	Roger C. Harris; Karin Söderlund; Eric Hultman	1992	874
Bangsbo et al., (2006)	Physical and metabolic demands of training and match-play in the elite football player	Jens Bangsbo; Magni Mohr; Peter Krustrup	2006	754
Rodriguez et al., (2016)	Nutrition and athletic performance	Nancy R. Rodriguez; Nancy M. DiMarco; Susie Langley	2016	717
Hultman et al., (1996)	Muscle creatine loading in men	E. Hultman; K. Soderlund; J. A. Timmons; G. Cederblad; P. L. Greenhaff	1996	608
Spencer et al., (2005)	Physiological and metabolic responses of repeated-sprint activities - Specific to field-based team sports	Matt Spencer; David Bishop; Brian Dawson; Carmel Goodman	2005	600
Wang et al., (2013)	Glycine metabolism in animals and humans: implications for nutrition and health	Weiwei Wang; Zhenlong Wu; Zhaolai Dai; Ying Yang; Junjun Wang; Guoyao Wu	2013	516
Wallimann, Uwe., (2011)	The creatine kinase system and pleiotropic effects of creatine	Theo Wallimann; Malgorzata Tokarska-Schlattner; Uwe Schlattner	2011	510
Maughan et al., (2018)	IOC consensus statement: dietary supplements and the high-performance athlete	Ronald J. Maughan; Louise M. Burke; Jiri Dvorak; D. Enette Larson-Meyer; Peter Peeling; Stuart M. Phillips; Eric S. Rawson; Neil P. Walsh; Ina Garthe; Hans Geyer; Romain Meeusen; Luc van Loon; Susan M. Shirreffs; Lawrence L. Spriet; Mark Stuart; Alan Vernec; Kevin Currell; Vidya M. Ali; Richard G.M. Budgett; Arne Ljungqvist; Margo Mountjoy; Yannis Pitsiladis; Torbjørn Soligard; Uğur Erdener; Lars Engebretsen	2018	509

A Tabela 5 apresenta os pesquisadores mais produtivos em estudos sobre suplementação de creatina. O pesquisador canadense Darren Candow ocupa o primeiro lugar, seguido pelo brasileiro Bruno Gualano. O Canadá se destaca com três pesquisadores entre os dez mais produtivos, representando a maioria no ranking. O Brasil aparece como o segundo país mais representado, com dois pesquisadores.

Table 5 - The most productive researchers in creatine.

Researcher	Filiation	Country	nº of articles
Darren Candow	University of Regina	Canada	70
Bruno Gualano	University of São Paulo	Brazil	65
Mark A. Tarnopolsky	McMaster university	Canada	49
Sergej Ostojic	University of Agder	Norway	49
Jeffrey Stout	College of Health Professions and Sciences	USA	48
Scott Forbes	University of Regina	Canada	46
Chi-Chang Huang	National Taiwan Sport University	Taiwan	44
Philip D. Chilibeck	University of Saskatchewan	Canada	43
Hamilton Roschel	University of São Paulo	Brazil	39
Peter Hespel	Katholieke Universiteit Leuven	Belgium	39

DISCUSSION

The growth of scientific production on creatine has been highlighted since the 1990s, with a significant increase in the 21st century. The United States stands out as the country with the highest volume of publications, as well as being home to the world's most productive scientific journals and universities.

Curiously, in the ranking of the ten most productive researchers, the majority are Canadians. Although recent studies, such as that by Sun et al., (2023), have carried out bibliometric analyses involving compounds such as taurine, creatine, carnosine and anserine related to metabolic syndrome, our research is pioneering in offering a more detailed bibliometric analysis focused specifically on creatine supplementation.

Scientific production on sports nutrition has grown steadily since the beginning of the 21st century (Kiss et al., 2021). This increase has also been observed in different sports, such as soccer (Plakias et al., 2024), basketball (Sofyan et al., 2022), kickboxing (Silva Duarte et al., 2024), handball (Ibáñez et al., 2020; Prieto et al., 2015) and taekwondo (Sousa et al., 2024).

The global growth in publications on the subject from the 1990s onwards can be attributed to the publication of the first article proving the ergogenic effect of creatine supplementation (Harris et al., 1992), which stands out as the third most cited article in this area.

Uiversity of São Paulo stands out as the academic institution with the largest number of published studies on creatine supplementation. It also leads scientific production on topics such as hypertension (Lou et al., 2023), dental caries (Lui et al., 2024), Olympic combat sports (Franchini et al., 2018) and taekwondo (Sousa et al., 2024).

This prominence is largely due to the work of two highly productive researchers, Bruno Gualano and Hamilton Roschel, both linked to USP and listed among the world's top ten experts in publications on creatine supplementation.

The United States stands out as the country with the largest number of published studies on creatine supplementation. In addition, they lead scientific production in several other areas, including Parkinson's (Li et al., 2023), Alzheimer's (Li et al., 2023), neuroscience (Xu et al., 2022), obesity (Khan et al., 2016), sports psychology (Coimbra et al., 2022), osteoporosis (Wu et al., 2021) and caffeine (Contreras-Barraza et al., 2021).

These data reinforce that the United States is not only a pioneer in creatine research, but also plays a leading role in several scientific disciplines.

The field of Sports Sciences is the most widely investigated in relation to creatine supplementation. According to Haff (2010), Sports Sciences is a multidisciplinary field, encompassing exercise physiology, biomechanics, motor control and development, sports psychology, sports nutrition, among others, with the aim of optimizing sports performance.

This shows that most studies on creatine supplementation focus on analyzing or reviewing its effects as an ergogenic resource in sport and exercise.

Secondly, there is the area of Nutrition and Dietetics, which, according to Sweileh et al (2014), investigates dietary patterns with the aim of promoting health. In the case of creatine, this scientific interest is also related to its consumption through foods such as meat, fish and other animal products (Andres et al., 2017).

The scientific journal "Nutrients" published the most articles on creatine supplementation. On the other hand, the Journal of Strength & Conditioning Research stood out with publications related to caffeine (Contreras-Barraza et al., 2021), while the European Journal of Applied Physiology led in research on protein consumption (Xu et al., 2022a).

However, we suggest that future bibliometric studies be carried out on beta-alanine supplementation in order to broaden the understanding of its scientific production profiles.

The three most cited studies were: 1) Arginine metabolism and nutrition in growth, health and disease (n = 980) (Wu et al., 2009), 2) Establishment and identification of small cell lung cancer cell lines having classic and variant features (n = 955) (Carney et al., 1985) and 3) Elevation of creatine in resting and exercised muscle of normal subjects by creatine supplementation (n = 874) (Harris et al., 1992).

These data indicate that the classic studies are the most referenced in the area. Analyzing the number of citations can provide evidence of the quality of a study and help to identify areas and topics that have received the most scientific attention to date (Gontijo et al., 2022).

Of the ten most productive authors, the majority are Canadian (n = 4), although the United States is the country with the highest total volume of publications. This indicates a large number of North American researchers interested in the topic, despite the fact that Canadians are the most productive individually. Brazilian researcher Bruno Gualano ranks second, a result consistent with the findings of Sun et al., (2023), who analyzed the bibliometrics of compounds such as taurine, creatine, carnosine and anserine in studies related to metabolic syndrome.

CONCLUSION

Scientific production related to creatine supplementation focuses mainly on investigating its effects on improving sports performance. Researchers from universities in various countries have shown a continuing interest in studying this supplementation.

The use of creatine as an object of research dates back to the 1950s, with two periods of significant growth in the volume of publications: the first, during the 1990s, and the second, in the 21st century.

DECLARATION OF CONFLICTS OF INTEREST

We declare that this study is not sponsored in any way that could influence its results.

ACKNOWLEDGEMENTS

Although this is not a funded study, co-author Jonatas Deivyson Reis da Silva Duarte would like to thank the Coordination for the Improvement of Higher Education Personnel Foundation (CAPES) for making a grant available.

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5 - Hospital Universitário Júlio Muller, Cuiabá, Brasil.

Authors' e-mails
mknj.cba@hotmail.com
jonatas00013@hotmail.com
michellejkommers@gmail.com
fettcarlos@gmail.com
fettwaleria@gmail.com

Corresponding author:
Jonatas Deivyson Reis da Silva Duarte
jonatas00013@hotmail.com

Recebido para publicação em 13/03/2025
Aceito em 12/06/2025