MedCrave Step into the World of Research International Journal of Complementary and Alternative Medicine

Review Article

Open Access CrossMark

Carbohydrates in sports performance

Abstract

This article highlights the relevance of carbohydrates as the main source of energy for performance in sports. It is stressed that the correct intake of carbohydrates before, during and after exercise is vital to optimize performance, avoid fatigue and speed up recovery. Not only are carbohydrates critical for maintaining energy during exercise, but they also play a crucial role in adapting to training and decreasing the risk of injury and overtraining. Additionally, it is pointed out that the quality of sleep and hydration are additional elements that favor the optimal performance of the athlete. In addition to the influence of carbohydrates, lipids and proteins on energy metabolism, underlining the relevance of the effectiveness of metabolic pathways for high-intensity activities. It is proposed that tailoring nutritional strategies to the particular needs of each athlete can lead to noticeable improvements in performance and overall health. Finally, it can be deduced that a correct intake of carbohydrates not only impacts physical condition, but also mood and cognitive function, underlining the importance of carbohydrates in sports and muscle rehabilitation. This knowledge provides a firm basis for practical suggestions based on sports nutrition studies.

Keywords: carbohydrates, energy, exercise, sport, nutrition, metabolism

Volume 18 Issue 4 - 2025

Diego David Cabrera,[1] Michelle Castro,[1] Luisa Alfaro Lemos,[1] Andrés Jenuer Matta,[2] Diana Carolina Zambrano Ríos[3]

[1]Professional student in sports, Faculty of Education and Sports Sciences, Escuela Nacional del Deporte, Cali, Colombia
[2]Biologist, Faculty of Education and Sport Sciences, Institución Universitaria Escuela Nacional del Deporte, Cali, Colombia
[3]Bacteriologist, Faculty of Education and Sport Sciences, Institución Universitaria Escuela Nacional del Deporte, Cali, Colombia

Correspondence: Diana Carolina Zambrano Ríos, Faculty of Education and Sports Sciences, National School of Sports, Cali, Colombia, Tel +57 3153067698

Received: June 12, 2025 | **Published:** August 05, 2025

Introduction

Carbohydrates are the most abundant macromolecules on our planet and in living beings; they are composed of carbon, hydrogen and oxygen, and fulfill various functions in the living organism, of which their metabolic participation as an energy substrate for obtaining energy in the form of adenosine triphosphate (ATP) can be highlighted. According to Bermúdez et al.,[1] carbohydrates are organic chemicals widely distributed in nature, and carbohydrates are divided into three main groups according to their structures: simple sugars (monosaccharides and disaccharides), such as glucose or sucrose (glucose and fructose); complex carbohydrates, such as glycogen, starch and cellulose, which are multiple conjugated glucose molecules; and glycoconjugates, which are modified forms of glucose covalently bound to proteins (glycoproteins) or lipids (glycolipids), which are involved in important functions, such as immunity, and as components of cell membranes.[2]

Once ingested, carbohydrates are broken down by chewing and saliva enzymes that degrade the bonds, turning large molecules into small swallows. Gastric juices in the stomach and in the small intestine, pancreatic juices, fulfill the function of breaking the glycosidic bonds of oligosaccharides, while in the small intestine, enzymes sucrase, lactase, galactose, among others, will break the bonds between disaccharides to leave loose monosaccharides, to be absorbed in the small intestine and transported by the bloodstream to the different cells of the body. The way carbohydrates are broken down and their glycemic index are important factors to consider in athletes' diets, as they affect energy availability during exercise and subsequent recovery.[3]

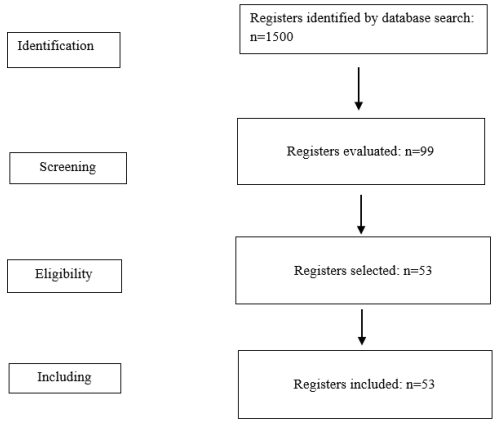
To understand the above, it is important to have a complete understanding of how the Krebs cycle develops. This begins with the formation of citrate from acetyl-CoA and oxaloacetate. The citrate is converted to isocitrate, which is metabolized to α-ketoglutarate, producing NADH and CO2. α-ketoglutarate is converted to succinyl-CoA, producing more NADH and CO2. Succinyl CoA is converted to succinate, producing GTP (or ATP) and CoA, then succinate is oxidized to fumarate, producing FADH2. Fumarate is converted to malate, which is then oxidized to oxaloacetate, producing NADH and starting the cycle again, to produce ATP, the body's energy currency, allowing cells to obtain the energy needed to carry out their vital functions. The efficiency of these metabolic pathways is crucial for physical performance, especially in high-intensity and long-lasting activities,[4] which not only allows glucose to enter cells, but its activity also regulates the efficiency of these metabolic processes, influencing the availability of energy during exercise.

Once absorbed, carbohydrates are transported through the bloodstream and enter thanks to the presence of glucose transporters (GLUT); there are several types of GLUT, each with specific functions: GLUT1 is found in almost all tissues and is responsible for basal glucose uptake; GLUT2, present in the liver and pancreas, facilitates glucose uptake during high blood glucose; GLUT4, predominantly in skeletal muscle and adipose tissue, is regulated by insulin and plays a key role in glucose uptake during and after exercise.[5] Once inside the cells, glucose is processed through aerobic and anaerobic metabolic pathways that include glycolysis, krebs cycling and oxidative phosphorylation. Glycolysis is a vital process for rapid energy production in situations where oxygen is scarce.[2] Although ATP production is less efficient in these areas, its ability to generate energy quickly makes it an essential component of energy metabolism, especially in sports and high-intensity physical activities.[6]

Finally, the objective of this research was to carry out a systematic review that would allow us to understand how carbohydrate intake influences before, during and after exercise, since carbohydrates are a primary source of energy for exercise. Understanding how to optimize your intake can lead to significant improvements in athletes' athletic performance, post-exercise recovery, and overall health. In addition, it can help to personalize nutritional strategies according to the specific needs of each type of sport and athlete, resulting in better preparation and overall performance, understanding the role of carbohydrates in recovery helps reduce the risk of injury and accelerates the recovery process after intense exercise. Examining how adequate carbohydrate intake can influence an individual's mood, stress, and cognitive function provides an approach that will allow us to comprehensively address the importance of carbohydrates as a source of energy, which could be applied to improve athletic performance, as well as muscle recovery processes. This knowledge can be applied to optimize athletic

performance and improve recovery after physical exertion, providing a solid basis for practical and research-based recommendations.

Methods



Search strategy

In this study, an investigation of articles was carried out with a systematic review, meta-analysis, contained in the statement (PRISMA), with free full texts and publication dates no older than 5 years, on carbohydrate intake before, during and after exercise as a source of energy, a computer search was carried out in PubMed (from May 13, 2024 to May 28, 2024), taking as references from analysis articles in English and Spanish, using a combination of keywords: 'Carbohydrates', 'Energy', 'Exercise', 'Sport', 'Nutrition', 'Metabolism', 'Hydration'.

Inclusion and exclusion criteria

To be more suitable for inclusion and subsequent review, the selected articles had to meet the following criteria: full texts, free, publication dates no older than 5 years, talk about carbohydrate intake before, during and after exercise as a source of energy. The records found in PubMed are 43 of which 5 were chosen, which met the ideal criteria already described.

Development

Carbohydrates are the main source of quick energy, for movement, growth, tissue repair, and heat production; likewise; When we perform a physical activity of more than an hour, it is advisable to consume carbohydrates before, during and after exercise, which maintains blood glucose and thus achieve the same or greater physical performance. Carbohydrates should be present in greater proportion in our diet, since their main function is to serve as a source of energy, to the central nervous system that only depends on them to perform its function; Liver and muscle are responsible for muscle contraction and relaxation that produces a movement based on the acquisition of energy mainly in carbohydrates.

Functional chemical groups

Carbohydrates are organic biomolecules and we call them organic because they will be composed mainly of Carbon, Hydrogen, Oxygen also called Carbohydrates, Carbohydrates or Saccharides, the word carbohydrates refers to the sweetness that any of these carbohydrates have when they are tasted. They are divided into functional groups such as hydroxyl (-OH), aldehyde (-CHO), keto (C=O), ester (-COO-), carboxylic acid (-COOH), glycosidic acid (R-O-R') and sulfhydryl (-SH).

Hydroxyl (-OH) is responsible for making carbohydrates more soluble in water. Aldehyde (-CHO) is crucial for the formation of glycosidic bonds and the chemical reactivity of monosaccharides. Keto (C=O) is involved in the formation of complex carbohydrates and glycoconjugates, while ester (-COO-) helps form complex carbohydrates and glycoconjugates. Carboxylic groups are present in modified carbohydrates and their products, such as free fatty acids. Glycosidic bonds are formed through the reaction of hydroxyl groups on monosaccharides, and sulfhydryl groups can participate in the modification and function of glycoproteins and glycolipids. These functional groups affect the structure, function, and metabolism of carbohydrates, influencing the solubility, reactivity, and formation of complex carbohydrates, as well as their interaction with other biomolecules.

The energy that carbohydrates give us comes from the nutritional cycle of that food pyramid that we have in living beings. They are important because they allow us to develop different metabolic reactions that have a single purpose: the production of energy, which are:

Monosaccharides

I. Glucose

II. Fructose

III. Galactose

Disaccharides

I. Sucrose

II. Polysaccharides

Carbohydrate sources

It is important to differentiate carbohydrates since not all carbohydrates are the same, and neither is the process it exerts in our body.

I. Foods with a high GI: these are simple sugars (sugar, jam, fruit, etc.).

II. Foods with low GI: (pasta, rice, dairy, etc.).

Let us make it clear that the most important thing is the individualization of each of the athletes since each one has different weight, height, position and the intensity of the competition is always variable according to the importance of the individualization of nutrition in the athlete population.[7]

For those athletes with the goal of losing weight or reducing fat, limiting carbohydrate intake can be beneficial during low-intensity, long-duration exercise, thus facilitating fat loss while adjusting performance to their individual goals, limiting carbohydrate intake before selected low-intensity sessions and/or moderating daily carbohydrate intake can improve mitochondrial function and fat oxidative capacity.[8] It is also important to know that nutritionists do not make promises of performance as this can affect athletes psychologically. As the competitive level increases, the greater the intensity at which the efforts are made and the greater the number of competitions per season. Therefore, if this expense is not compensated, it will directly affect the performance of athletes. The routines of food, preparations, quantities and menu are selected directly by the nutritionist, who takes into account each player and the training sessions carried out before and after a match.

Citation: Cabrera DD, Castro M, Lemos LA, et al. Carbohydrates in sports performance. *Int J Complement Alt Med.* 2025;18(4):148–154.
DOI: 10.15406/ijcam.2025.18.00741

Carbohydrate digestion and transport

The rapid absorption and good digestion will allow the athlete to have energy in training and competition, for this it is necessary to have an intake of carbohydrates that provide this quickly and without causing damage as stated.[9] Carbohydrate intake was found to be effective in maintaining technique and improving certain performance measures without causing intestinal discomfort,[9] in addition to that other articles describe that the intake of carbohydrates and polyunsaturated fats helps maintain intestinal integrity,[10] apart from that for endurance exercise, there is a need for new food products that are solid but easy to swallow and that provide a large dose of CHO without gastrointestinal upset (ingestion of a large amount of sugar solution can cause gastrointestinal upset due to its high osmolarity).[11]

The amount and timing of intake also play an important role in optimizing performance and recovery, in this study it is shown that the intake of 120 g/h of carbohydrates during a mountain marathon can limit neuromuscular fatigue and improve recovery of high-intensity running capacity compared to lower intakes.[12] Performance optimization is not only dependent on carbohydrates, it has been shown with this study that a protein and carbohydrate intake during recovery improves performance compared to carbohydrates alone, possibly due to a better nitrogen balance suggesting that protein synthesis contributes to better performance the next day.[13] As we know, carbohydrates are the main source of glucose, which is stored in the form of glycogen in the liver and muscles. This glucose is essential for maintaining energy levels during exercise, skipping a carbohydrate-rich breakfast negatively affects performance in high-intensity exercises performed in the afternoon, regardless of compensation in food intake during lunch.[14]

Carbohydrate metabolism

According to Alghannam et al.,[15] carbohydrate and fat metabolism is tightly regulated during prolonged exercise. Carbohydrates are metabolized faster than other molecules in the body, as it does compared to proteins that have a slower metabolism period, this can favor carbohydrates when used to seek sports performance taking into account that the high-protein diet improved fat oxidation, but compromises high-intensity performance, while the high-carbohydrate diet showed improvements in performance and biomarkers of training adaptation,[16] although there are studies showing that glucose is the body's preferred energy substrate during endurance exercise. Currently, most athletes use high-glycemic index (HGI) CHO for pre-exercise and/or in-exercise nutrition due to its rapid breakdown that dramatically increases blood glucose availability.[17]

Other studies suggest that the impact on performance may not be as effective in all contexts, showing that in order for exogenous CHOs to exert their effect as an ergogenic aid, they must be consumed, absorbed, distributed, uptaked, and oxidized preferentially over other substrates available by skeletal muscle for use in ATP turnover.[18] The consumption of carbohydrates before exercise can cause the fat metabolizing pathways not to be activated very adequately, compared to fasting, the intake of carbohydrates or proteins before exercise affects the oxidation of substrates, but not performance or hunger during cycling.[19] The metabolization of carbohydrates will depend on the intensity and duration of the exercises, as mentioned by Rothschild and Plews[20]. Acute carbohydrate intake reduces fat oxidation, improves performance in prolonged exercise but not in short exercises.[20]

When performing physical activity, our muscles need glucose to obtain energy in the muscle, during this process they include the supply of glucose to the muscle from the capillary bed through the interstitium, the transport of glucose to the muscle by GLUT4 and the phosphorylation of glucose within the muscle by hexokinase II (HKII).[21]

Importance of carbohydrates in sports

Carbohydrates may be effective for exercise performance and recovery, but palatability and gastrointestinal discomfort should be considered Karayigit et al.,[22] are still essential for athletic performance due to their primary source of energy, glucose, which is used to nourish muscles and the brain during physical activities which is stored in the body as glucose, which helps maintain blood glucose levels and provides continuous energy, muscle glycogen content reaches low levels at the time of exhaustion, leading to the conclusion that muscle glycogen was a key determinant of endurance capacity Noakes[23]. Carbohydrates are also crucial for recovery after exercise, helping to replenish glucose levels and facilitate muscle repair.

Adequate carbohydrate intake can prevent fatigue, regulate metabolism and improve endurance in endurance sports, exercise capacity with fructose compared to glucose makes total carbohydrate oxidation higher with the combination of fructose and Podlogar et al.,[6]. For athletes and active people, it's important to adjust carbohydrate intake based on the type, intensity, and duration of exercise. A balanced diet with healthy carbohydrates is crucial for optimal performance and good recovery, underlined by research showing that improved endurance capacity with a high carbohydrate load, is associated with a temporary change in the utilization of stores other than glycogen stores and is closely linked to the content of the glycogen store closest to actin and myosin (intramyofibrillary glycogen) Jensen et al.,[24] in addition to the fact that a diet rich in carbohydrates will generate better endurance in performance as they point out.[25]

The mental factor in high-performance athletes plays a crucial role for competition and carbohydrates can reduce mental fatigue as Zhu et al.,[26] (mindfulness intervention together with CHO increased mindfulness and improved repeated sprint performance, reducing mental fatigue.[26] The body may have to resort to less efficient energy sources, such as fats, to fuel the body when we have a lower carbohydrate intake, this without affecting performance. Delayed carbohydrate eating can maintain high rates of fat oxidation without affecting performance in high-intensity exercise, although the acute effects remain inconclusive.[27]

As far as possible, each physical activity should be started with a diet rich in carbohydrates low in fat and protein, adherence to a low-carbohydrate diet was associated with lower efficiency and economy of exercise compared to a high-carbohydrate diet.[28]

It is important for an athlete to consume carbohydrates because it provides energy to meet the increased energy demand during peak week is essential to maximize performance, improve physical appearance and facilitate recovery, which is crucial for success in bodybuilding competitions Homer et al.,[29] also allows muscle recovery after physical activity since muscle glycogen is the most important source of energy for athletes, as pointed out by María Margaret, carbohydrate consumption can improve physical performance, particularly for active and healthy individuals. However, the benefits of consuming carbohydrates in sedentary people are less evident, we must take into account the different diets consumed by different athletes, which is why María-Margaret et al., also looked at various dietary approaches, such as the Mediterranean diet and the DASH diet, which may affect insulin sensitivity and cardiovascular risk; indicating that macronutrient composition, including carbohydrates,

Citation: Cabrera DD, Castro M, Lemos LA, et al. Carbohydrates in sports performance. *Int J Complement Alt Med.* 2025;18(4):148–154.
DOI: 10.15406/ijcam.2025.18.00741

can have a significant impact on insulin resistance, and in turn a higher intake of fiber and unsaturated fats, and a lower intake of carbohydrates and sugar improves hepatic insulin sensitivity in adults with metabolic syndrome.[30]

In these studies, positive effects have been found in protein and/or carbohydrate supplementation since consuming the carbohydrate intake of 5 g/kg BM/d is not enough to fully recover muscle glycogen 24 hours after prolonged exercise. Intakes of 7 and 10 g/kg BM/d allow complete recovery Namma-Motonaga et al.,[31] carbohydrate supplementation after glycogen depletion improved performance in some studies Henselmans et al.,[32] this intake also improves body composition, recovery after exercise since high carbohydrate intake is beneficial for fatigue and recovery in ultratrails Arribalzaga et al.,[33] also generates an adaptation to exercise, in addition these supplements come with additions of compounds that, according to their distributors, improve physical and body condition. Some are really effective and others are not, this depends not only on the type and concentration of carbohydrates but also on the sporting level at which you are training and the individual conditions of each athlete.

The results indicated that carbohydrate solutions have an overall positive effect on performance, with variations depending on the concentration and type of solution, as well as the fitness level of the subjects Bourdas et al.,[34] for ultra-endurance athletes it is supremely important to have at their disposal a source of carbohydrates of rapid consumption and absorption allowing the ingestion of concentrated carbohydrate gels during prolonged exercise that promotes the availability of carbohydrates and improves the performance of the test time Salvador et al.,[35] similarly Clark et al.,[36] tells us how gels and other carbohydrate sources can be used effectively to improve performance in prolonged exercise, providing useful information for nutritional planning in sport Carbohydrate intake attenuates the reduction in critical power during prolonged exercise, providing new insights into exercise-related fatigue.

Carbohydrates, of course, provide extra energy, especially in the last moments of the game. Rinsing and spitting out carbohydrate solutions during exercise can improve athletes' performance,[37] as stated by Yang et al.,[38] carbohydrate rinsing before exercise improves contraction strength in multi-joint resistance exercises, in other studies carbohydrate mouthwash was found to improve muscle endurance in high-intensity exercise (80% of 1 RM) but not at low intensity (40% of 1 RM). It does not affect heart rate, perceived exertion, glucose, or felt arousal.[22]

It is critical to note that carbohydrate replenishment during prolonged exercise is essential for performance, proper recovery is equally important for maintaining health and improving long-term performance. Nutrition in recovery is also very important to minimize the risk of injury or unexplained underperformance syndrome (UUPS) from overuse. You should consider fuel replenishment (carbohydrates), rehydration (fluids), and repair (protein),[39] as the main sources of energy for muscles during exercise are carbohydrates (CHO) and fats. During prolonged exercise, both steady and intermittent, these two macronutrients are critical for fueling muscle activity. Exogenous carbohydrates, which are those ingested through the diet, play a crucial role in regulating the use of muscle carbohydrates during exercise, the higher the fiber intake and the better physical fitness, the higher the chances of high hs-CRP levels.[40]

It is important to understand that athletes have to adapt to the consumption of carbohydrates so that they do not affect their digestion and thus their performance, as mentioned by different studies. Carbohydrates in preventing fatigue and improving performance during prolonged exercise, increasing carbohydrate intake during exercise, and using dietary strategies for gut adaptation have minor effects on gastrointestinal status and performance in highly trained endurance athletes.[41]

Exogenous carbohydrates influence athletic performance in several ways

I. Improved Performance and Endurance Capacity: Carbohydrate intake has been shown to have an effect on microecological factors that can improve post-exercise performance and recovery by modulating energy metabolism, reducing oxidative stress, and improving immune function Yang et al.,[42] before and/or during physical activity and endurance capacity. This is because carbohydrates provide a quick source of energy that can be used by the muscles during prolonged exercise.

II. Fatigue prevention: Carbohydrate intake helps prevent depletion of endogenous carbohydrate stores and hypoglycemia, which are factors that contribute to fatigue during exercise. Carbohydrate and protein supplementation may reduce post-exercise muscle damage, although it does not improve endurance capacity in endurance runners.[43]

III. Carbohydrate Oxidation: During prolonged exercise, the oxidation of exogenous carbohydrates (such as those ingested through sports drinks or gels) can be high, meaning that the body can use these carbohydrates efficiently to meet energy demands.

IV. Regulation of Muscle Metabolism: Exogenous carbohydrates also play a role in regulating muscle carbohydrate utilization, facilitating better performance through the relocation of glucose transporters and improving glucose absorption and utilization in the muscles. Maintaining adequate blood glucose levels is crucial for optimal performance, with trehalose improving cycling performance after prolonged exercise and is an adequate source of carbohydrates for activities up to 2 hours in duration.[44]

Why is hydration important for an athlete?

During training and tournaments, athletes lose important fluids and electrolytes, such as sodium and potassium through sweat, therefore, without adequate hydration they could face episodes of dehydration with the consequent physical exhaustion, reducing the athlete's performance, dehydration not only affects muscle endurance and postural control, but can also increase heart rate and tremor. Thus compromising precision and performance in sports that require high concentration, such as archery,[45] when we talk about sports drinks we are not referring to those commonly called "isotonic'' whose sodium intake is lower than necessary and excessive in sugars, drinks with carbohydrates and proteins are more effective in restoring endurance capacity in athletes with limited time to recover than only water and electrolytes,[46] it is advisable to hydrate an activity as follows 3 hours before the activity, ingest 5 to 7 ml of fluid per kg of weight (for 65 kg, consume 455 mml of liquid). The drink should contain carbohydrates that provide sustained energy, and sodium that stimulates thirst and helps absorb water.

It depends on your level of exertion, the temperature of the day, the humidity, your hydration level before the race, etc. The rule is to drink before you are thirsty, and there is nothing better than to start hydrating the days before to ensure that you will not suffer from dehydration, have breakfast with a glass of water, and continue drinking water until half an hour before the activity. If the day is hot, do not forget that you should drink water every 20 minutes during the activity, to replace

Citation: Cabrera DD, Castro M, Lemos LA, et al. Carbohydrates in sports performance. *Int J Complement Alt Med.* 2025;18(4):148–154.
DOI: 10.15406/ijcam.2025.18.00741

the loss of fluids through sweat. And when they are done, they should drink more water, however carbohydrate mouthwashes can also be used to improve this function as carbohydrate rinses showed a slight improvement.[50–60]

Conclusion

Carbohydrate intake before, during, and after training is critical to ensure that the body has enough energy to perform at its best, prevent fatigue, and speed recovery. This allows for better adaptation to training and a reduction in the risk of injury and overtraining. Carbohydrates are the base of our food pyramid, and therefore they should play a main role in our diet, since they are responsible for generating energy to be able to develop our daily activity optimally and also help us regulate our brain activity. This must be accompanied by sleep so that the athlete can have optimal performance, "maintain adequate hydration and sleep quality"[45] accompanying this with the nocturnal restriction of carbohydrates, thus improving fat metabolism that can help in weight reduction and sports performance, this being important for an adequate intake of other nutrients.[47]

As a recommendation, it is suggested that food intake be organized at times to regulate metabolism and make a better digestion process, for example at 7 AM. A meal of 2 or 2.5 gr. of carbohydrates per kg, of weight, this guarantees the amount of glycogen for that player. It is important to select foods that the athlete is familiar with, dietary manipulation affects the gut microbiota and performance. The high-carbohydrate diet is associated with improved microbial performance and stability.[48] This is important because gut microbial stability is associated with increased endurance performance in athletes who perform dietary periodization. Limit the consumption of foods rich in sugar, rich in fat, rich in fiber, very spicy or spicy foods and alcoholic beverages, we must take into account the flavors and products that can generate rejection in players or at the time of their hydration; that is why train the digestive system, with time since if a player consumes more carbohydrates than he is used to, he could have gastrointestinal discomfort during the match; It would be recommended to give an amount of 30 to 60 carbohydrates per hour.

We must understand that carbohydrate consumption depends purely on physical activity and the athlete's position or form of play because dietary intake varies according to the level of competition and playing position, probably due to different metabolic demands.[49] Likewise, Podlogar and Wallis[6] point out, carbohydrate availability remains crucial for performance in intensive and prolonged exercise. A more personalized approach to carbohydrate intake is recommended.

Author contributions

All the authors involved in the acquisition and interpretation of the results read and approved the final manuscript; Cabrera DD, Castro M, Alfaro L, Matta AJ, Zambrano DC, conducted the experimental methodology; Cabrera DD, Castro M, Alfaro L, Matta AJ, Zambrano DC, analyzed the data; Cabrera DD, Castro M, Alfaro L, Matta AJ, Zambrano DC wrote, revised, and edited the manuscript.

Acknowledgements

None.

Conflicts of interest

The authors declare that there are no conflicts of interest.

References

1. Bermúdez V, Bermúdez F, Arraiz N, et al. Molecular biology of glucose transporters: classification, structure and distribution. *Venezuelan Archives of Pharmacology and Therapeutics*. 2007;26(2):76–86.
2. Chandel NS. Carbohydrate Metabolism. *Cold Spring Harb Perspect Biol*. 2021;13(1):a040568.
3. Marroquín Cabrera BI, Martínez Chicas GC, Martínez Hernández MV, et al. *Importance of carbohydrate consumption in high-performance sports athletes*. Universidad del Salvador Repository. 2023.
4. Mata Ordoñez F, Grimaldi Puyana M, Sánchez Oliver AJ. Replenishment of muscle glycogen in the recovery of the athlete. *SPORT TK-EuroAmerican Journal of Sport Sciences*. 2019;8(1):57–66.
5. Koepsell H. Glucose transporters in brain in health and disease. *Pflugers Archiv*. 2020;472(9):1299–1343.
6. Podlogar T, Wallis GA. New Horizons in Carbohydrate Research and Application for Endurance Athletes. *Sports Med*. 2022;52(1):5–23.
7. Hernandez A, Garcia J, Martínez A, et al. The Effects of Football Practice on Nutritional Status and Body Composition in Children: A Systematic Review and Meta-Analysis. *Nutrientes*. 2021;13(8):2562.
8. Tiller NB, Roberts JD, Beasley L, et al. International Society of Sports Nutrition Position Stand: nutritional considerations for single-stage ultra-marathon training and racing. *J Int Soc Sports Nutr*. 2019;16(1):50.
9. Dobbin N, Richardson D, Myler L, et al. Effects of a 12% carbohydrate beverage on tackling technique and running performance during rugby league activity: A randomized, placebo-controlled trial. *PLoS One*. 2022;17(1):e0262443.
10. Etxebarria N, Beard NA, Gleeson M, et al. Dietary intake and gastrointestinal integrity in runners performing high-intensity exercise in the heat. *Int J Sport Nutr Exerc Metab*. 2021;31(4):314–320.
11. Shihara K, Taniguchi H, Akiyama N, et al. Easy to Swallow Rice Cake as a Carbohydrate Source during Endurance Exercise Suppressed Feelings of Thirst and Hunger without Changing Exercise Performance *J Nutr Sci Vitaminol (Tokyo)*. 2020;66(2):128–135.
12. Urdampilleta A, Arribalzaga S, Viribay A, et al. Effects of 120 vs. 60 and 90 g/h Carbohydrate Intake during a Trail Marathon on Neuromuscular Function and High Intensity Run Capacity Recovery. *Nutrients*. 2020;12(7):2094.
13. Dahl MA, Areta JL, Jeppesen PB, et al. Coingestion of protein and carbohydrate in the early recovery phase, compared with carbohydrate only, improves endurance performance despite similar glycogen degradation and AMPK phosphorylation. *J Appl Physiol (1985)*. 2020;129(2):297–310.
14. Metcalfe RS, Thomas M, Lamb C, et al. Omission of a carbohydrate-rich breakfast impairs evening endurance exercise performance despite complete dietary compensation at lunch. *Eur J Sport Sci*. 2021;21(7):1013–1021.
15. Alghannam AF, Ghaith MM, Alhussain MH. Regulation of Energy Substrate Metabolism in Endurance Exercise. *Int J Environ Res Public Health*. 2021;18(9):4963.
16. Furber M, Pyle S, Roberts M, et al. Comparing Acute, High Dietary Protein and Carbohydrate Intake on Transcriptional Biomarkers, Fuel Utilisation and Exercise Performance in Trained Male Runners. *Nutrients*. 2021;13(12):4391.
17. Dudar MD, Bode ED, Fishkin KR, et al. Pre-Sleep Low Glycemic Index Modified Starch Does Not Improve Next-Morning Fuel Selection or Running Performance in Male and Female Endurance Athletes. *Nutrients*. 2020;12(9):2888.

18. McMahon G, Thornbury A. Ingestion of Carbohydrate Prior to and during Maximal, Sprint Interval Cycling Has No Ergogenic Effect: A Randomized, Double-Blind, Placebo Controlled, Crossover Study. *Nutrients*. 2020;12(8):2223.

19. Rothschild JA, Kilding AE, Broome SC, et al. Pre-Exercise Carbohydrate or Protein Ingestion Influences Substrate Oxidation but Not Performance or Hunger Compared with Cycling in the Fasted State. *Nutrients*. 2021;13(4):1291.

20. Rothschild JA, Kilding AE, Plews DJ. What Should I Eat before Exercise? Pre-Exercise Nutrition and the Response to Endurance Exercise: Current Prospective and Future Directions. *Nutrients*. 2020;12(11):3473.

21. Malone J, Hulton A, Maclaren D. Exogenous carbohydrate and regulation of muscle carbohydrate utilisation during exercise. *Eur J Appl Physiol*. 2021;121(5):1255–1269.

22. Karayigit R, Eser MC, Gur F, et al. Carbohydrate Mouth Rinse Increases High but Not Low Intensity Repetitions to Failure in Resistance-Trained Males. *Nutrients*. 2022;14(4):875.

23. Noakes TD. What Is the Evidence That Dietary Macronutrient Composition Influences Exerci McMahon se Performance? A Narrative Review. *Nutrients*. 2022;14(4):862.

24. Jensen R, Ørtenblad N, Stausholm MH, et al. Heterogeneity in subcellular muscle glycogen utilisation during exercise impacts endurance capacity in men. *J Physiol*. 2020;598(19):4271–4292.

25. O'Brien L, Collins K, Webb R, et al. The Effects of Pre-Game Carbohydrate Intake on Running Performance and Substrate Utilisation during Simulated Gaelic Football Match Play. *Nutrients*. 2021;13(5):1392.

26. Zhu Y, Sun F, Li C, et al. Acute Effects of Brief Mindfulness Intervention Coupled with Carbohydrate Ingestion to Re-Energize Soccer Players: A Randomized Crossover Trial. *Int J Environ Res Public Health*. 2020;17(23):9037.

27. Podlogar T, Free B, Wallis GA. High rates of fat oxidation are maintained after the sleep low approach despite delayed carbohydrate feeding during exercise. *Eur J Sport Sci*. 2021;21(2):213–223.

28. Baart AM, Schaminee H, Mensink M, et al. Effect of a low carbohydrate, high fat diet versus a high carbohydrate diet on exercise efficiency and economy in recreational male athletes. *J Sports Med Phys Fitness*. 2023;63(2):282–291.

29. Homer KA, Cross MR, Helms ER. An examination of the associations between nutritional peaking strategies in physique sport and competitor characteristics. *J Int Soc Sports Nutr*. 2024;1(1):2377178.

30. Laine S, Sjöros T, Garthwaite T, et al. Daily standing time, dietary fiber, and intake of unsaturated fatty acids are beneficially associated with hepatic insulin sensitivity in adults with metabolic syndrome. *Front Endocrinol*. 2024;15:1272886.

31. Namma Motonaga K, Kondo E, Osawa T, et al. Effect of Different Carbohydrate Intakes within 24 Hours after Glycogen Depletion on Muscle Glycogen Recovery in Japanese Endurance Athletes. *Nutrients*. 2022;14(7):1320.

32. Henselmans M, Bjørnsen T, Hedderman R, et al. The effect of carbohydrate intake on strength and resistance training performance: A systematic review. *Nutrients*. 2022;14(4):856.

33. Arribalzaga S, Viribay A, Calleja González J, et al. Relationship of Carbohydrate Intake during a Single-Stage One-Day Ultra-Trail Race with Fatigue Outcomes and Gastrointestinal Problems: A Systematic Review. *Int J Environ Res Public Health*. 2021;18(11):5737.

34. Bourdas DI, Souglis A, Zacharakis ED, et al. Meta-Analysis of Carbohydrate Solution Intake during Prolonged Exercise in Adults: From the Last 45+ Years' Perspective. *Nutrients*. 2021;13(12):4223.

35. Salvador AF, McKenna CF, Alamilla RA, et al. Potato ingestion is as effective as carbohydrate gels to support prolonged cycling performance. *J Appl Physiol*. 2019;127(6):1651–1659.

36. Clark IE, Vanhatalo A, Thompson C, et al. Dynamics of the power-duration relationship during prolonged endurance exercise and influence of carbohydrate ingestion. *J Appl Physiol*. 2019;127(3):726–736.

37. Remchak M, Piersol K, Bhatti S, et al. Considerations for Maximizing the Exercise "Drug" to Combat Insulin Resistance: Role of Nutrition, Sleep, and Alcohol. *Nutrients*. 2021;13(5):1708.

38. Yang TJ, Shiu YJ, Chen CH, et al. Carbohydrate Mouth Rinses before Exercise Improve Performance of Romanian Deadlift Exercise: A Randomized Crossover Study. *Nutrients*. 2024;16(8):1248.

39. Kim J, Kim EK. Nutritional Strategies to Optimize Performance and Recovery in Rowing Athletes. *Nutrients*. 2020;12(6):1685.

40. Su MZ, Lee S, Shin D. Association of Dietary Fiber and Measures of Physical Fitness with High-Sensitivity C-Reactive Protein. *Nutrients*. 2024;16(6):888.

41. King AJ, Etxebarria N, Ross ML, et al. Short-Term Very High Carbohydrate Diet and Gut-Training Have Minor Effects on Gastrointestinal Status and Performance in Highly Trained Endurance Athletes. *Nutrients*. 2022;14(9):1929.

42. Yang K, Chen Y, Wang M, et al. The Improvement and Related Mechanism of Microecologics on the Sports Performance and Post-Exercise Recovery of Athletes: A Narrative Review. *Nutrients*. 2024;16(11):1602.

43. Liang Y, Chen Y, Yang F, et al. Effects of carbohydrate and protein supplement strategies on endurance capacity and muscle damage of endurance runners: A double blind, controlled crossover trial. *J Int Soc Sports Nutr*. 2022;19(1):623–637.

44. De Oliveira NG, de Oliveira LF, da Silva RP, et al. Trehalose Improved 20-min Cycling Time-Trial Performance After 100-min Cycling in Amateur Cyclists. *Int J Sport Nutr Exerc Metab*. 2024;34(4):199–206.

45. Esen O, Walshe I, Goodall S. Energy intake, hydration status, and sleep of world-class male archers during competition. *J Int Soc Sports Nutr*. 2024;21(1):2345358.

46. Goldstein ER, Stout JR, Wells AJ, et al. Carbohydrate-Protein drink is effective for restoring endurance capacity in masters class athletes after a two-Hour recovery. *J Int Soc Sports Nutr*. 2023;20(1):2178858.

47. Sakamoto T, Ueda SY, Nakahara H. Effects of Short-Term Nighttime Carbohydrate Restriction Method on Exercise Performance and Fat Metabolism. *Nutrients*. 2024;16(13):2138.

48. Furber MJW, Young GR, Holt GS, et al. Gut Microbial Stability is Associated with Greater Endurance Performance in Athletes Undertaking Dietary Periodization. *mSystems*. 2022;7(3):e0012922.

49. Chryssanthopoulos C, Souglis A, Tsalouhidou S, et al. Dietary Intake of Soccer Players before, during and after an Official Game: Influence of Competition Level and Playing Position. *Nutrients*. 2024;16(3):337.

50. American College of Sports Medicine, Sawka MN, Burke LM, Eichner ER, et al. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39(2):377–390.

51. Best R, Crosby S, Berger N, et al. The Effect of Isolated and Combined Application of Menthol and Carbohydrate Mouth Rinses on 40 km Time Trial Performance, Physiological and Perceptual Measures in the Heat. *Nutrients*. 2021;13(12):4309.

52. Cano A, Ventura l, Martinez G, et al. Analysis of sex-based differences in energy substrate utilization during moderate-intensity aerobic exercise. *Eur J Appl Physiol*. 2022;122(1):29–70.

Citation: Cabrera DD, Castro M, Lemos LA, et al. Carbohydrates in sports performance. *Int J Complement Alt Med.* 2025;18(4):148–154.
DOI: 10.15406/ijcam.2025.18.00741

53. Gratwicke M, Miles KH, Pyne DB, et al. Nutritional Interventions to Improve Sleep in Team-Sport Athletes: A Narrative Review. *Nutrientes*. 2021;13(5):1586.

54. Herman C, Sandri Heidner G, Wentz LM, et al. Influence of modified starches on mental performance and physical activity following an exhaustive bout of exercise. *Physiol Rep*. 2024;12(3):e15927.

55. Karayigit R, Ali A, Rezaei S, et al. Effects of carbohydrate and caffeine mouth rinsing on strength, muscular endurance and cognitive performance. *J Int Soc Sports Nutr*. 2021;18(1):63.

56. Naderi A, Gobbi N, Ali A, et al. Carbohydrates and Endurance Exercise: A Narrative Review of a Food First Approach. *Nutrients*. 2023;15(6):1367.

57. Podlogar T, Bokal Š, Cirnski S, et al. Increased exogenous but unaltered endogenous carbohydrate oxidation with combined fructose-maltodextrin ingested at 120 g h^{-1} versus 90 g h^{-1} at different ratios. *Eur J Appl Physiol*. 2022;122(11):2393–2401.

58. Podlogar T, Cirnski S, Bokal Š, et al. Addition of Fructose to a Carbohydrate-Rich Breakfast Improves Cycling Endurance Capacity in Trained Cyclists. *Int J Sport Nutr Exerc Metab*. 2022;32(6):439–445.

59. Prieto Bellver G, Díaz Lara J, Bishop DJ, et al. A Five-Week Periodized Carbohydrate Diet Does Not Improve Maximal Lactate Steady-State Exercise Capacity and Substrate Oxidation in Well-Trained Cyclists compared to a High-Carbohydrate Diet. *Nutrients*. 2024;16(2):318.

60. Viribay A, Arribalzaga S, Mielgo Ayuso J, et al. Effects of 120 g/h of Carbohydrates Intake during a Mountain Marathon on Exercise-Induced Muscle Damage in Elite Runners. *Nutrients*. 2020;12(5):1367.

Citation: Cabrera DD, Castro M, Lemos LA, et al. Carbohydrates in sports performance. *Int J Complement Alt Med.* 2025;18(4):148–154.
DOI: 10.15406/ijcam.2025.18.00741