QhaliKay REVISTA DE CIENCIAS DE LA SALUD
Una publicación de la Universidad Técnica de Manabí
ISSN: 2588-0608
https://revistas.utm.edu.ec/index.php/QhaliKay | revista.qhalikay@utm.edu.ec



**Review**

Mayo-Agosto 2022;6(2):73-84
https://doi.org/10.33936/qkrcs.v6i2.4534

# *Isotonic sports drinks: formulation and physiological effects of their consumption*

*Bebidas deportivas isotónicas: formulación y efectos fiosiológicos de su consumo*

*Yanelis Ruiz[1]* Mario A. García[2]*

## *Abstract*

*When practicing intense physical exercise for more than an hour, it is recommended to counteract the loss of water and electrolytes and provide an energy substrate by drinking isotonic sports beverages. These contain carbohydrates and mineral salts at the same osmotic pressure as blood, facilitating the rapid absorption of their constituents. Its consumption before, during, and after prolonged physical exercise is more effective than water in preventing dehydration, helping to maintain performance during exercise, delaying the onset of fatigue, and accelerating recovery. Based on the demand for more natural foods, there is an interest from the food industry to produce isotonic drinks from ingredients such as fruits, cereals, among others. In this sense, this review describes some aspects of the formulation and physiological effects of consuming this type of drink.*
***Keywords:*** *isotonic drink; electrolyte; osmolality.*

## *Resumen*

*Al practicar ejercicio físico intenso durante más de una hora, se recomienda contrarrestar la pérdida de agua y electrolitos y proporcionar un sustrato energético mediante el consumo de bebidas deportivas isotónicas. Estas contienen carbohidratos y sales minerales a la misma presión osmótica que la sangre, facilitando la rápida absorción de sus constituyentes. Se ha demostrado que su consumo antes, durante y después del ejercicio físico duradero es más efectivo que el agua en la prevención de la deshidratación, ayuda a mantener el rendimiento durante el ejercicio, retrasa la aparición de la fatiga y aceleran la recuperación. A partir de la demanda de alimentos más naturales, existe un interés de la industria alimentaria por producir bebidas isotónicas a partir de ingredientes como frutas, cereales, entre otros. En este sentido, en la presente revisión se describen algunos aspectos sobre la formulación y efectos fisiológicos del consumo de este tipo de bebida.*
***Palabras clave:*** *bebida isotónica; electrolito; osmolalidad.*

**Dirección para correspondencia: yaneruiz1992@gmail.com*
*Artículo recibido el 24-03-2022 Artículo aceptado el 21-06-2022 Artículo publicado el 28-06-2022*
*Fundada 2016 Facultad de Ciencias de la Salud de la Universidad Técnica de Manabí, Ecuador.*

## Introduction

The water balance of the body at rest is maintained thanks to an adequate balance between the inflows and outflows of fluids[1]. Nevertheless, when physical exercise is performed, lost fluids must be replenished before symptoms of dehydration occur since it affects sports performance and increases the risk of injury[2].

Although when practicing physical exercise for less than an hour, it is enough to drink water before, during, and after to maintain an adequate hydration, when the exercise is intense and long-lasting or is practiced in a particularly hot environment, the body loses water and electrolytes rapidly through sweat and increases energy consumption, with a consequent decrease in blood sugar concentration and glycogen stores[3]. Therefore, during prolonged physical exercise, it is advisable to counteract the loss of these substances by consuming isotonic sports drinks.

Thus, starting in the 1960s, at the University of Florida, a formula of carbohydrates, electrolytes, and water was developed to improve the performance of a group of American football players and to prevent dehydration caused by intense physical activity[4].

[1] *Universidad de Chile, Facultad de Ciencias Químicas y Farmacéuticas, Máster en Ciencia y Tecnología de los Alimentos, Santiago de Chile, Chile, yaneruiz1992@gmail.com, https://orcid.org/0000-0001-9889-322X*
[2] *Universidad Técnica de Manabí, Facultad de Ciencias de la Salud, Doctor en Ciencias de los Alimentos, Departamento de Ciencias Biológicas, Portoviejo, Manabí, Ecuador, mario.garcia@utm.edu.ec, https://orcid.org/0000-0002-0304-9665*

To date, the development of new formulations that are increasingly more effective and more widely accepted by consumers has continued. This increase is mainly due to the increased competitiveness in the market of the different brands, among the best known are Gatorade® (The Quaker Oats Co.), Isostar® (Wander), Powerade® (Coca-Cola), and Aquarius® (Coca-Cola).

Commercial sports drinks usually contain ingredients such as preservatives, colorants, artificial sweeteners, aromatizers, and flavorings, used to improve palatability and to prolong shelf life, but they have been severely questioned for their potential harm to consumer health[5]. Based on the demand for more natural drinks, there is an interest from the food industry to produce isotonic drinks from fruits, cereals, and other natural ingredients. The use of these raw materials is advantageous, not only because they add natural flavor and color, but also they provide vitamins, minerals, and antioxidant substances that enrich the product nutritional profile. In this sense, this review describes some aspects of the formulation and physiological effects of consuming this type of drink.

## Requirements of water, carbohydrates, and electrolytes during the practice of physical exercise

Fatigue has been defined as the inability to maintain a given or expected force or power and is unavoidable during intense exercise[6]. During the competition, the objective of nutritional strategies is to improve performance, which is achieved by minimizing the influence of factors that cause fatigue, which are hyperthermia, dehydration, depletion of carbohydrate stores, electrolyte imbalance, and gastrointestinal discomfort[7].

In healthy individuals, water is the largest component of the body. Its homeostasis is essential for virtually all physiological functions. Therefore, it is of vital importance to replace the water lost during the practice of physical exercise. Effective fluid replacement relies primarily on the ingestion of appropriate beverages throughout the day. Thirst is implicated in water intake, although certain behavioral habits also have an important influence on drinking. Sports drinks play an important role in this regard, as their flavor profile encourages fluid intake, and their electrolyte content is crucial for retention of ingested water[8].

In general, the administration of carbohydrates and electrolytes is not considered necessary for physical activity practiced for less than one hour, but in events of longer duration and to supply energy, prevent dehydration and promote recovery after exercise, this kind of supplementation plays a fundamental role[3].

For the sustained practice of sports, energy must be provided in the form of carbohydrates. Its addition to beverages consumed before, during, and after intense and prolonged exercise:

- Provides an energy substrate for the muscles. A substantial portion of the carbohydrates ingested during exercise is available for oxidation, but there appears to be a maximum rate (approximately 1 g/min) at which it can be oxidized, even when much larger amounts are consumed[9].
- Prevents the development of hypoglycemia by maintaining or increasing the concentration of circulating glucose. Most of the common types of carbohydrates, such as glucose, sucrose, and glucose polymers, are effective in maintaining blood glucose concentration, due to their high glycemic index[10].
- Prevents liver but not muscle glycogen depletion[11,12]. In addition, it can contribute to the restoration of endogenous glycogen stores after exercise[13].
- Stimulates the absorption of water and sodium in the small intestine.
  - Thus, the most important effect of carbohydrate intake is the improvement of physical performance during prolonged exercise, since the mechanisms responsible for improving endurance capacity have been related to the prevention of hypoglycemia, maintenance of a high rate of carbohydrate oxidation, and, in some studies, sparing of glycogen[14].
  - There has been much debate about the value of adding electrolytes to fluids ingested during exercise. Normally, electrolyte replacement during exercise is not a priority and it is

considered that, if a balanced diet is followed, its concentrations may be restored in the post-exercise period.

– However, the addition of sodium to beverages consumed during physical exercise promotes rehydration as it:

- Stimulates the absorption of glucose and water in the small intestine. This is crucial when a quick replacement is needed, such as during exercise.
- Stimulates the voluntary intake of fluids: it reduces the capacity of the drink to quench thirst and improves its palatability. Sodium, being the main electrolyte in the extracellular fluid, is closely involved in the homeostatic control of body water and, therefore, in many of the sensory signals and mechanisms that control water intake[15].
- Favors fluid retention: by raising plasma osmolality, urine production is reduced, allowing the body to retain more of the water ingested, which allows the restoration of the volume of extracellular fluid after exercise[15].
- Prevents hyponatremia, a dangerous condition given in conditions of hyperhydration, during which the serum concentration of sodium is abnormally low due to a dilution effect[16].

Although only sodium plays an active role in the absorption of water and carbohydrates, it has been speculated that the inclusion of potassium would improve intracellular water replenishment after exercise and thus promote rehydration, but there is little evidence to support its inclusion[17]. Potassium, which is the main osmotically active cation in the intracellular space, does not seem to play a role like sodium in maintaining water balance[15].

Although there is some loss of potassium in sweat, an increase in its plasma concentration is the normal response to exercise, due to the release of potassium from working muscles and liver, as well as from red blood cells and other tissues subjected to damage on the membrane[7]. Intense exercise may cause hyperkalemia (potassium plasma concentration above 5.5 mM), followed by abrupt hypokalemia (potassium plasma concentration below 3.5 mM) on exercise cessation, which can pose a threat to stability of the myocardium and may contribute to sudden cardiac death[18]. Given this situation, additional potassium increase through fluid intake during exercise may be counterproductive.

In the case of magnesium, a slight decrease in its plasma concentration is generally observed during exercise, which appears to be the result of a redistribution of storage sites[7]. Exercise cramps are commonly associated with decreased plasma magnesium concentration; however, magnesium supplementation for preventing these cramps has not shown any efficacy[19].

Although alterations of the distribution of electrolytes, such as potassium and magnesium, within the tissues have implications for the maintenance of their function, replacement is generally not a problem since the movements between compartments are reversed in the post-exercise period[7].

## Ingestion and absorption of drinks

### Gastric emptying

In situations where a rapid supply of exogenous nutrients or water is required, it is essential that any beverage ingested is rapidly emptied from the stomach and rapidly and completely absorbed in the small intestine. As these are critical elements for the effectiveness of any sports drinks, they are formulated in such a way as to optimize these processes.

Gastric emptying is the transfer of stomach contents into the small intestine. The speed at which it occurs is considered the main limiting factor for the assimilation of ingested fluids. The gastric emptying rate of liquids is faster than that of solids. Therefore, nutrients and water supplied as beverages are more rapidly absorbed and assimilated than are ingested as solid food[15].

The main determinant of the rate of gastric emptying of a drink are the volume and the composition. If the liquid is low in nutrients (for example, water), there is an exponential relationship between the volume and the rate of emptying: the higher the volume, the higher the rate. In contrast, if the fluid is rich in nutrients, the rate of gastric emptying will be considerably slower and not exponential. In this case, the energy density of the beverage is the main inhibitory regulator of gastric emptying; increasing the energy density proportionally decreases the rate of gastric emptying. Carbohydrates are the main source of energy in sports drinks, but other nutrients such as protein, fat, and alcohol delay emptying to the same extent[15]. Any carbohydrate content in the drink will slow emptying, an effect that becomes evident from a concentration of approximately 40 g/L[3]. Although increasing the carbohydrate content of the drink decreases the rate of gastric emptying, it usually results in a higher rate of carbohydrate delivery to the duodenum. To some extent, increasing beverage osmolality also slows gastric emptying, but this effect is very slight at typical sports drink concentrations.

**Intestinal absorption**

The process of absorption of the components of a drink occurs in the small intestine. Water absorption is a passive process that occurs by osmotic action only, but it is closely related to active solute transport. If sodium and sugars are also present in the ingested fluid, then active transport mechanisms operate, which promote water absorption. This, in turn, promotes the absorption of solutes through a phenomenon known as solvent drag[15].

Sodium is absorbed into the cell by various mechanisms, but the main one is by co-transport with glucose and amino acids. This means that the efficient absorption of sodium depends on the absorption of these organic solutes. Water diffuses in response to the osmotic gradient created by sodium[15].

In the small intestine, glucose is directly absorbed by an active, $Na^+$-dependent transport system, while a series of hydrolytic enzymes rapidly digest disaccharides and polysaccharides to their monomeric forms, which are then efficiently transported across the mucosa by transportation systems.

The rate of glucose absorption through the active transport system reaches its maximum at a glucose concentration of 200 mmol/L, but tends to continue to increase through mechanisms such as diffusion down the concentration gradient and solvent drag, until 555 mmol/L. That is, the maximum rate of glucose absorption occurs in solutions with glucose concentrations of 3.6 to 10.0%[15].

In contrast, fructose is absorbed by a facilitated transport mechanism, its absorption rate is approximately 2/3 that of glucose. Moreover, since it tends to accumulate in the intestine, the intake of large amounts of fructose should be avoided, as it can cause gastrointestinal discomfort and diarrhea. There are no other nutrients, apart from carbohydrates and sodium, which are necessary to stimulate water absorption[15].

Osmolality plays a key role in the flow of water through the upper part of the small intestine. Water absorption is isotonic. That is, water is not absorbed until what has been ingested has been diluted to a level equal to the osmolality of the blood. The osmolality of blood serum varies slightly within individuals and from person to person, but it is usually considered to be 287 mOsm/kg. Any solution with an osmotic pressure equivalent to that of serum is considered isotonic, if its osmolality is lower, hypotonic, and if it is higher, hypertonic[3].

The net flux of water is largely determined by the osmotic gradient between the luminal contents and the intracellular fluid of the cells lining the intestine. The effect is concentration-dependent; the maximum rate of water absorption occurs when solute concentrations result in a slightly hypotonic solution (200 to 250 mOsm/kg)[3]. The time required to achieve isotonicity reduces the rate of net water absorption.

Therefore, when the content of the lumen is significantly hypertonic, water is secreted from the plasma into the intestine by osmotic action; this is a dehydrating effect that results in lower rates of water absorption[3]. Hypertonic solutions are eventually absorbed. This delay, along with the initial net movement of water from the circulation to dilute luminal contents, makes hypertonic solutions ineffective in promoting fast rehydration.

## Isotonic sports drinks. Formulation

Isotonic sports drinks are those that contain carbohydrates and electrolytes at the same osmotic pressure as blood. There is no international standard definition that includes formulation requirements for carbohydrate and electrolyte solutions; however, entities such as the European Food Safety Authority (EFSA) and the Food Standards of Australia and New Zealand have made recommendations in this regard[20,21].

### Carbohydrates

Carbohydrates should be the main source of energy and it is recommended that they provide 80 to 350 kcal/L of beverage, which corresponds to a concentration range of 20 to 87 g/L. At least 75% of the energy must be derived from metabolizable carbohydrates, characterized by a high glycemic index (glucose, glucose polymers, and sucrose)[20]. Another recommendation establishes that they must contain between 50 and 100 g/L of glucose, fructose, glucose syrup, maltodextrin, and/or sucrose, with the amount of fructose being lower than 50 g/L[21].

The amount of carbohydrates in the sports drink will be that which allows a balance between the energy content and the inhibition of gastric emptying. A too low concentration will not optimize the flavor of the drink and will not supply enough carbohydrates to enhance exercise performance. On the other hand, excess carbohydrates delay gastric emptying and intestinal absorption, can cause gastrointestinal disorders (>10% w/v) and a feeling of satiety, and may impair palatability[15,22].

Sports drinks typically contain between 60 and 80 g of carbohydrates per liter. When deciding which carbohydrate(s) will be used, the key factors are molar weight (MW) (and therefore its contribution to osmolality), sweetening power, and electrolyte content[3]. Some types of commercially available carbohydrates are[3]:

- Glucose: its low MW (180 g/mol) produces a greater impact on osmolality It has low electrolyte content.
- Fructose: with a low MW (180 g/mol), it is not rapidly absorbed in the intestine and is not readily available for muscle use since it is metabolized in the liver.
- Sucrose: MW of 342 g/mol, it has a lower contribution to osmolality per gram than monosaccharides. It has a negligible quantity of electrolytes. In acid solutions, it is inverted into glucose and fructose, reducing its MW by half, and causing an increase in osmolality.
- Glucose syrup: it is a complex mixture of sugars produced by hydrolysis of starch. Available in various degrees of dextrose equivalence (DE), from 42 to 95 DE. As DE increases, average MW decreases and sweetness increases. It has a moderate electrolyte content.
- High fructose corn syrup: produced from the partial enzymatic conversion of glucose to fructose. It has an approximate composition of 42% fructose, 52% glucose, and 6% higher saccharides. Its MW is like that of glucose syrup with 95 DE. It is sweeter than glucose syrup and it has minimal electrolyte content. The presence of fructose is not desirable, but low levels of this syrup does not provide more fructose than partially inverted sucrose.
- Maltodextrins: produced by the partial hydrolysis of starch. They range of DE is from 15 to 30 and have a very high average MW (typically 1100 g/mol for 15 DE). They have a high content of electrolytes and virtually no sweetness.

Several papers have been published regarding the merits of different carbohydrates, but aside from the above considerations, any commercially available sugars could be used. The exception is fructose, which, being absorbed more slowly and metabolized in the liver, is not readily available for oxidation and can cause gastrointestinal discomfort[3].

Mixing different carbohydrates can be beneficial: 1) by providing solutes that are absorbed by different mechanisms, it can maximize the rate of absorption of sugars and water in the small intestine; 2) it has implications on the taste, which can positively influence the amount of drink consumed; 3) allows better management of the osmolality of the product during its formulation. That is why in most commercial sports drink various forms of carbohydrates are combined[11].

### Electrolytes

Ideally, hydrating drinks should have a sodium concentration like that of sweat, but since the sodium content of sweat varies widely between people, a single formulation is not possible. The sodium concentration of most sports drinks ranges from 10 to 30 mmol/L, while most fruit juices and soft drinks contain virtually no sodium[13].

The Australia and New Zealand food standards establishes a minimum sodium concentration of 10 mmol/L and the EFSA recommends 20-50 mmol/L (460-1150 mg/L)[20,21]. It can be added in the form of salts, such as sodium chloride or sodium citrate[3,21]. Sodium intake in very low amounts discourages the need to drink, stimulates urine production, and therefore delays the hydration process[22]. Very high concentrations of sodium can lead to the perception of the drink as too salty, an important defect that can reduce voluntary consumption. Due to its importance, this problem must be evaluated during the formulation of any new hydration drink[17].

Although only sodium plays an active role in the absorption of water and carbohydrates, sports drinks are often also fortified with potassium, magnesium, calcium, and chloride, which are added in concentrations like those in sweat[3]. It is possible to use salts such as[3,21]: potassium (chloride, citrate, phosphate); calcium (chloride, lactate), and magnesium (chloride, sulfate). However, the presence of these do not have a discernible impact on the absorption of water and carbohydrates and may produce an increase in the osmolality of the solution[15].

### Other components

Sports drinks were originally developed as relatively simple solutions of carbohydrates and electrolytes in known amounts. However, today it is common to find ingredients such as high-intensity sweeteners, aromas, flavorings, and colorants, added to improve palatability, in commercial sports drinks.

Vitamins are also included in many formulations. Some concern has been fueled by the idea that fluid loss during sweating increases the loss of water-soluble vitamins, or that the high metabolic demands of training athletes increase vitamin requirements. However, the available research indicates that sweat is not a significant route of loss of these vitamins. Although thiamin is linked to carbohydrate metabolism, it has not been shown to improve this by supplementation with any of the $B_2$ complex vitamins[23].

Antioxidant vitamins A, C, and E can help in scavenging free radicals that form within the muscle, which occurs at a higher rate during strenuous physical activity. Therefore, they could be valuable for post-exercise recovery drinks[3].

The addition of other ingredients such as starch, amino acids, proteins, lipids, glycerol, alcohol, caffeine, organic acids, and herbs have also been investigated. They have been studied for their ability to induce increased fluid absorption or increased performance, but so far without convincing success.

The addition of amino acids to a sports drink does not offer any benefits for sports performance. Amino acids in solution are not stable during storage for long periods and, even under the best circumstances, their presence may negatively affect the overall palatability and acceptance of beverages. The addition of caffeine to beverages limits the effectiveness of hydration due to its diuretic effect. Beer has been considered as a beverage with the potential to stimulate hydration, both due to its composition and its high acceptance among consumers but, as with caffeine, alcohol has diuretic properties.

Carbonation promotes gastric emptying since carbon dioxide occupies an additional volume in the stomach. However, carbonated drink consumed during exercise has a strong negative impact on its acceptability, due to the burning sensation in the throat caused by the presence of high volumes of $CO_2$[22].

Lastly, sports drinks are not good vehicles for delivering nutrients because the doses that can be included without adversely affecting taste and physiological efficacy are quite small[15].

## Osmolality

The osmotic pressure of a solution is a colligative property, that is, it is proportional to the number of solute particles present in the solution. Most sports drinks are formulated to be isotonic and thus optimize absorption in the intestine, which favors the rapid assimilation of its constituents[24]. Although water absorption is optimal with slightly hypotonic solutions, as stated above, higher osmolality is unavoidable when adequate amounts of carbohydrate are incorporated into the sports drink[3].

An osmolality range between 200 and 330 mOsm/kg of water is recommended. Beverages with an osmolality of 300 mOsm ± 10% of the range (270-330 mOsm/kg of water) can be designated as isotonic[20]. However, the composition of the beverages and the nature of the solutes are just as important as the osmolality itself.

Hyperosmolality has a dehydrating effect and delays absorption. However, small variations are not clinically significant. Therefore, slightly hypertonic solutions with an osmolality of 340 to 400 mOsm/kg can still be effectively used as sports drinks[25].

Today's sports drinks are complex solutions of nonionic and ionic substances; the latter will dissociate to different degrees depending on their nature and the rest of the solutes present. The osmolality of formulated beverages can be estimated by calculations from tables available, for example, in the Handbook of Chemistry and Physics, The Merk Index, and The British Pharmacopeia. The osmolality of ingredients for which no data is available can be calculated from the osmolality of substances of similar MW and ionic character[3].

Theoretical estimates of osmolality should be checked by direct measurement with an osmometer. This equipment determines osmolality through the measurement of some colligative properties, such as melting point depression. A molar solution of a non-ionic substance will produce a freezing point depression of about 1.86 °C, but for ionic substances, the decrease will be 1.86 multiplied by the number of ionic components generated per molecule[3].

## Final formulation

Once the carbohydrate system and the salt content, which is close to the desired level, have been chosen, a first drink prototype can be proposed. The sweetness will then be adjusted by the addition of high-intensity sweeteners, a level of acidity will be selected, and flavor, color, and preservatives will be added at appropriate levels[3].

Afterwards, the osmolality must be set. A reduction can be achieved by substituting low MW sugars for a maltodextrin, or by reducing the total carbohydrate content. An increase can be achieved by making the opposite changes. Typically, 70% of the osmolality of the beverage is due to the carbohydrate content, 10% to salts, 15% to juice/flavor/acids/high-intensity sweeteners, and 5% to carbonation (if any)[3].

## Palatability

Physical activity alters the hedonic characteristics of beverages in a way that a beverage that may be preferable in sedentary conditions, may be rejected during exercise. For this reason, a properly formulated isotonic carbohydrate-electrolyte sports drink has organoleptic characteristics that are most valued when people are hot, sweaty, and thirsty. Therefore, it is essential to conduct sensory field surveys with athletes during and after physical activity. Aspects that require attention are sweetness, acidity, and flavor type and intensity[26].

Taste is a very important element in promoting voluntary fluid intake. Some flavorings added to hydration drinks mask the taste of salt. In addition to flavor, beverage temperature can affect a variety of sensory and physiological functions, directly influencing the volume consumed. Temperature of 15 °C is considered as ideal for fluid intake[26].

The palatability of sports drinks is measured in a variety of ways, either using scaling techniques (e.g., a 9-point verbal hedonic scale) or inferred from differences in voluntary fluid intake.

Achieving the optimal balance between sports drink efficacy and palatability is a significant challenge for manufacturers. From a food science perspective, sports drinks are relatively simple beverage systems, and that fact makes it difficult to manipulate the types and amounts of solutes without having an immediate and noticeable effect on palatability.

## Physiological effects of the consumption of isotonic sports drinks

### Beneficial effects

Research agrees that isotonic sports drinks, consumed before, during, and after prolonged and intense exercise or other strenuous physical activity, are more effective than water in preventing dehydration, helping to maintain exercise performance, delaying the onset of fatigue, and accelerating recovery[20,27,28]. For the restoration of carbohydrate and electrolyte levels, it is recommended to drink 120 to 180 mL of sports drinks every 15 minutes during vigorous exercise[29].

Some sports are especially demanding due to their duration and intensity, such as soccer, long-distance running, cycling, and tennis, among others. For example, when sports drinks were consumed before, during, and after playing tennis, the decrease in exertional capacity was minimal and performance was improved compared to situations in which the only liquid consumed was water[30].

The behavior of the plasma concentration of sodium during physical exercise is not distinguished by a specific response. Its change can be variable, meaning that hyponatremia or hypernatremia could occur or that there would be no alteration. However, it seems that, during too much exercise, an isotonic drink containing sodium can reduce the possibility of hyponatremia[31].

### Adverse effects

Isotonic drinks may have adverse effects if they are consumed in excess. They can cause a deterioration of dental enamel due to the erosive potential imparted by some compounds that appear in certain brands. Dental deterioration appears to be more related to the frequency of consumption than to the quantity consumed. Athletes belong to the highest risk group since with physical activity, fluids are lost and the volume of saliva is reduced, which is an important buffer for acids in the mouth. However, it is believed that the calcium content of isotonic drinks could protect against this erosive effect, which could justify their incorporation in the formulation[32].

### Isotonic sports drinks from natural products

Sports drinks available on the market often contain flavorings, sweeteners, and other synthetic compounds. Currently, and because of consumer demand for more natural products, the sports nutrition industry is looking for alternatives to traditional sports drinks.

The carbohydrate content of a fruit juice diluted at 50% is like that of a commercial isotonic sports drink, so it can be used for fluid replacement during exercise. Most juices lack the necessary electrolytes, so they can be fortified with sodium chloride. Fruit juices are easily accessible, affordable drinks that are widely accepted by consumers. A simple substitute for sports drinks like Gatorade and Powerade® could be diluted with 50% of apple juice and mixed with sodium chloride. Gatorade® contains 6% carbohydrates, while an apple juice diluted at 50% contains 5.9% carbohydrates, which is a very similar amount[33].

A diluted juice drink that is as effective as a commercial sports drink in rehydration and performance enhancement would not only have economic advantages, but it could provide additional beneficial nutrients and phytochemicals not found in commercial sports drinks[33].

It is possible to prepare a hydrating drink with natural ingredients, which can be cheaper and healthier and can produce beneficial effects on physical performance, in a similar way to commercial sports drinks. An example would be the mixture of 5 g of baking soda, 5 g of kitchen salt, 2 tablespoons of sugar, the juice of 2 citrus fruits, and 1 L of water[34]. The drawback is that its isotonicity cannot be guaranteed.

Several isotonic sports drinks have been developed from fruits, cereals, and other natural ingredients. An example of this is the isotonic sports drink designed by López et al.[35] from an apple concentrate with the addition of sodium, potassium, magnesium, and calcium salts, in addition to vitamins $B_1$, $B_2$, $B_6$, $B_{12}$, C, E, folic acid, niacin, pantothenic acid and biotin contained in the concentrate. An isotonic energy drink with almond milk can be obtained by blanching and crushing almonds, adding fruit juices or infusions, pasteurizing the mixture, correcting the loss of nutrients, and a final stage to adjust pH and osmolality, which is 275 mOsm/kg approximately[36].

Penggalih et al.[37] developed an isotonic sports drink from banana flour, with an osmolality of 269 mOsm/kg. Later, Afriani et al.[38] studied the effect of this drink on maintaining hydration, through the measurement of the level of electrolytes (chloride, sodium, and potassium) in plasma and urine. The product was able to maintain the body's normal electrolyte levels by reducing the amount of those electrolytes eliminated through urine.

An isotonic sports drink was also developed from pineapple (*Ananas comosus* L.) juice using a D-optimal blend design. The beverages with the highest percentages of sucrose and pineapple juice turned out to be the ones with the highest osmolality and sensory acceptance. A drink containing pineapple juice (34.0%; 628 mOsm/kg), distilled water (62.8%), sucrose (3.1%), and NaCl (0.1%; 20 mmol/L) was obtained, which had 7.7% of total sugars, an osmolality of 328 mOsm/kg and an adequate sensory acceptance[39].

Some researchers have focused on substituting synthetic food additives usually found in commercial sports drinks for natural substances. For example, Bovi et al.[40] were able to successfully produce an isotonic sports drink with a nanoemulsion of buriti oil as coloring agent, in substitution of artificial dyes. Similarly, Porfírio et al.[41] used a hydroethanolic extract of peel and pulp of *Myrciaria jaboticaba* to add dark red color to an isotonic beverage.

More recently, spray drying was applied to a mixture of honey, plant infusions, fruit juices, and salt, to prepare powdered isotonic sports drinks with enhanced antioxidant properties and a variety of colors and flavors, depending on the ingredients used in each formulation[42].

## Conclusions

The benefits of consuming isotonic sports drinks are proven in athletes and individuals who perform strenuous, long-lasting physical exercises or in very hot environments; however, its consumption should not be encouraged in people who only engage in moderate physical activity, especially children and adolescents. In addition, its consumption must be combined with a balanced diet that provides essential macro and micronutrients. Further research is required to personalize, by optimizing, the amount of each of the ingredients in isotonic drinks, based on individual preferences and exercise characteristics, and to develop alternatives to commercially available sports drinks using natural ingredients, following market trends.

## References

1. Jéquier E, Constant F. Water as an essential nutrient: the physiological basis of hydration. Eur J Clin Nutr [Internet]. 2010;64(2):115-23. Available from: https://doi.org/10.1038/ejcn.2009.111
2. Murray B. Hydration and physical performance. J Am Coll Nutr [Internet]. 2007;26(sup5):542S-8S. Available from: https://doi.org/10.1080/07315724.2007.10719656
3. Ashurst PR, Palmer Q. Miscellaneous topics. In: Chemistry and Technology of Soft Drinks and Fruit Juices, Ashurst PR (Ed.). Hereford, UK: John Wiley & Sons [Internet]. 2016. Available from: https://doi.org/10.1002/9781118634943.ch13
4. Cote-Menéndez M, Rangel-Garzón CX, Sánchez-Torres MY, Medina-Lemus A. Bebidas energizantes: ¿Hidratantes o estimulantes? Rev Fac Med [Internet]. 2011;59(3):255-66. Available from: http://www.scielo.org.co/pdf/rfmun/v59n3/v59n3a08.pdf
5. Cunliffe A, Begum R, Leverrit M, Konstantaki M. Effectiveness of commercial versus homemade sports drinks on fluid balance and exercise capacity during high-intensity intermittent exercise. Am J Sports Sci Med [Internet]. 2016;3(2):39-46. Available from: https://doi.org/10.12691/ajssm-3-2-3
6. Gleeson M. Biochemistry of exercise. In: Nutrition in Sport, Maughan RJ (Ed.). Oxford, UK: Blackwell Science Ltd. [Internet]. 2013. Available from: https://doi.org/10.1002/9781118692318.ch3
7. Maughan RJ. Fundamentals of Sports Nutrition: Application to Sports Drinks. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/4556chnu
8. Shirreffs SM, Maughan RJ. Water turnover and regulation of fluid balance. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/27m34w65
9. Jeukendrup AE. Carbohydrate feeding during exercise. Eur J Sport Sci [Internet]. 2008;8(2):77-86. Available from: https://doi.org/10.1080/17461390801918971
10. Scientific Committee on Food. Report of the Scientific Committee on Food on composition and specification of food intended to meet the expenditure of intense muscular effort, especially for sportsmen. Bruselas: Europäische Kommission [Internet]. 2001. Available from: https://ec.europa.eu/food/system/files/2020-12/sci-com_scf_out64_en.pdf
11. Aragón-Vargas LF. Metabolic and performance responses to carbohydrate intake during exercise. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, EE.UU.: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/3vmbrxnv
12. Gonzalez JT, Fuchs CJ, Smith FE, Thelwall PE, Taylor R, Stevenson EJ, Van Loon LJ. Ingestion of glucose or sucrose prevents liver but not muscle glycogen depletion during prolonged endurance-type exercise in trained cyclists. Am J Physiol-Endocrinol Metab [Internet]. 2015;309(12):E1032-39. Available from: https://tinyurl.com/bd78r977
13. Shirreffs SM. Post-exercise rehydration and recovery. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/yc3z4jby
14. Nicholas CW, Williams C, Lakomy HK, Phillips G, Nowitz A. Influence of ingesting a carbohydrate-electrolyte solution on endurance capacity during intermittent, high-intensity shuttle running. J Sports Sci [Internet]. 1995;13(4):283-90. Available from: https://doi.org/10.1080/02640419508732241
15. Leiper JB. Gastric emptying and intestinal absorption of fluids, carbohydrates, and electrolytes. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/2p8n7skf
16. Vrijens DMJ, Rehrer NJ. Sodium-free fluid ingestion decreases plasma sodium during exercise in the heat. J Appl Physiol [Internet]. 1999;86(6):1847-51. Available from: https://doi.org/10.1152/jappl.1999.86.6.1847
17. Pérez-Idárraga A, Aragón-Vargas LF. Postexercise rehydration: potassium-rich drinks versus water and a sports drink. Appl Physiol Nut Metab [Internet]. 2014;39(10):1167-74. Available from: https://doi.org/10.1139/apnm-2013-0434
18. Lindinger MI, Cairns SP. Regulation of muscle potassium: exercise performance, fatigue and health implications. Eur J Appl Physiol [Internet]. 2021;121(3):721-48. Available from: https://link.springer.com/article/10.1007/s00421-020-04546-8
19. Garrison SR, Korownyk CS, Kolber MR, Allan GM, Musini VM., Sekhon RK, Dugré N. Magnesium for skeletal muscle cramps. Cochrane Database Syst Rev [Internet]. 2012;9(CD009402). Available from: https://www.cochranelibrary.com/cdsr/doi/10.1002/14651858.CD009402.pub2/full

20. EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). Scientific Opinion on the substantiation of health claims related to carbohydrate-electrolyte solutions and reduction in rated perceived exertion/effort during exercise (ID 460, 466, 467, 468), enhancement of water absorption during exercise (ID 314, 315, 316, 317, 319, 322, 325, 332, 408, 465, 473, 1168, 1574, 1593, 1618, 4302, 4309), and maintenance of endurance performance (ID 466, 469) pursuant to Article 13 (1) of Regulation (EC) No 1924/2006. EFSA Journal [Internet]. 2011;9(6):2211. Available from: https://doi.org/10.2903/j.efsa.2011.2211
21. Food Standards Australia New Zealand. Australia New Zealand Food Standards Code - Standard 2.6.2 - Non-Alcoholic Beverages and Brewed Soft Drinks. Canberra: Food Standards Australia New Zealand [Internet]. 2017. Available from: https://www.legislation.gov.au/Details/F2017C00721/8d28b501-d2db-4daf-9df4-1b904be0201c
22. Murray R, Stofan J. Formulating carbohydrate-electrolyte drinks for optimal efficacy. In: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/2x6msudk
23. Horswill CA. Other ingredients: role in the nutrition of athletes. In: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/2h4uzuef
24. Williams MH. Nutrición para la salud la condición física y el deporte (Bicolor). Barcelona, Spain: Paidotribo [Internet]. 2002. Available from: https://tinyurl.com/cbz5bt8m
25. Brouns F, Kovacs E. Functional drinks for athletes. Trends Food Sci Technol. 1997;8:414-21. Available from: https://doi.org/10.1016/S0924-2244(97)01098-4
26. Maughan RJ. Physiological responses to fluid intake during exercise. En: Sports Drinks, Maughan RJ, Murray R (Eds.). Florida, USA: CRC Press [Internet]. 2000. Available from: https://tinyurl.com/2yp7bw8v
27. Shalesh FJ, Hasan UC, Jaaz AF. The effect of sport drink on some functional variables for soccer players. Int J Adv Res [Internet]. 2014;2(2):868-75. Available from: https://www.journalijar.com/uploads/945_IJAR-2830.pdf
28. Moreno IL, Pastre CM, Ferreira C, de Abreu LC, Valenti VE, Vanderlei LCM. Effects of an isotonic beverage on autonomic regulation during and after exercise. J Int Soc Sports Nutr [Internet]. 2013;10(1):1-10. Available from: https://doi.org/10.1186/1550-2783-10-2
29. Chatterjee A, Abraham J. A comprehensive study on sports and energy drinks. En: Sports and Energy Drinks, Grumezescu A, Holban AM (Eds.). Sawston, UK: Woodhead Publishing [Internet]. 2019. Available from: https://doi.org/10.1016/B978-0-12-815851-7.00015-2
30. Simulescu V, Ilia G, Macarie L, Merghes P. Sport and energy drinks consumption before, during and after training. Sci Sports [Internet]. 2019;34(1):3-9. Available from: https://doi.org/10.1016/j.scispo.2018.10.002
31. Marins JC, Dantas EHM, García JAV, Navarro SZ. Bebidas para deportistas y electrolitos plasmáticos. Arch Med Deporte [Internet]. 2001;23(86):621-6. Available from: https://tinyurl.com/8ze829bh
32. Ostrowska A, Szymański W, Kołodziejczyk Ł, Bołtacz-Rzepkowska E. Evaluation of the erosive potential of selected isotonic drinks: in vitro studies. Adv Clin Exp Med [Internet]. 2016; 25(6):1313-9. Available from: https://doi.org/10.17219/acem/62323
33. DeNysschen CA, Ford A, Rao T, Zimmerman B. The Physiological Effects of Gatorade® Versus Diluted Fruit Juice during Exercise: A Preliminary Study. J Food and Nutr [Internet]. 2014;1:1-6. Available from: https://doi.org/10.17303/jfn.2014.101
34. Bonilla, M. ¿Cómo hacer una bebida isotónica casera para después de hacer deporte? [Internet]. Available from: https://tinyurl.com/ycy2apn7 2016 [consulted 2020.06.21].
35. López L, Wittig de Penna E, Bunger A, Fuenzalida R, Giacchero C, Santana R. Development and optimization of an isotonic sports drink. Arch Latinoam Nutr [Internet]. 1994;44(4):256-63. Available from: https://pubmed.ncbi.nlm.nih.gov/8984966/
36. Pons A, Aguiló A, Tur JA, Tauler P, Piña A, Cases N. Bebida isotónica energética y procedimiento de obtención. España: Universitat de Les Illes Balears [Internet]. 2004. Available from: https://patents.google.com/patent/ES2231710T3/es
37. Penggalih MHST, Gardjito M, Sofro ZM. The effect of banana flour as an isotonic drink to maintain hydration status. Int Food Res J [Internet]. 2011;18(4):1559-61. Available from: http://www.ifrj.upm.edu.my/18%20(04)%202011/(49)IFRJ-2011-061.pdf

38. Afriani Y, Putri KR, Penggalih MHST, Kandarina I, Sofro ZM. Effect of Banana Isotonic Drink to Maintain Hydration Through Urine and Blood Electrolytes. Pak J of Nutr [Internet]. 2015;14(8):453-6. Available from: https://docsdrive.com/pdfs/ansinet/pjn/2015/453-456.pdf
39. Ruiz Y, Rodríguez Y, García MA. Desarrollo de una bebida deportiva isotónica a partir de jugo de piña. Cienc Tecnol Alim [Internet]. 2018;28(3):7-13. Available from: https://www.revcitecal.iiia.edu.cu/revista/index.php/RCTA/article/view/31/27
40. Bovi GG, Petrus RR, Pinho SC. Feasibility of incorporating buriti (Mauritia flexuosa L.) oil nanoemulsions in isotonic sports drink. Int J of Food Sci Technol [Internet]. 2017;*52*(10):2201-09. Available from: https://tinyurl.com/2p8f8mm3
41. Porfírio MCP, Gonçalves MS, Borges MV, Leite CXDS, Santos MRC, Silva AGD, Silva MVD. Development of isotonic beverage with functional attributes based on extract of *Myrciaria jabuticaba* (Vell) Berg. Food Sci Technol (Campinas) [Internet]. 2019;40:614-20. Available from: https://tinyurl.com/3x2yb837
42. Tomczyk M, Zaguła G, Dżugan M. A simple method of enrichment of honey powder with phytochemicals and its potential application in isotonic drink industry. LWT [Internet]. 2020;125:109204. Available from: https://tinyurl.com/y6fd6ymw