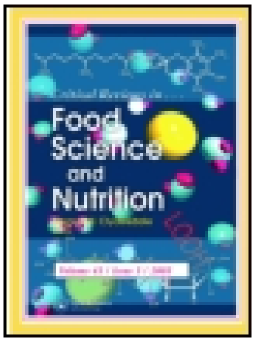

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REVIEW

Ergogenic potential of foods for performance and recovery: a new alternative in sports supplementation? A systematic review

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ABSTRACT
In recent years, there have been studies in the literature reporting the ergogenic effect of some different foods on sports performance. Given the reasonable number of studies in which some food has shown improvement in some physiological variables related to physical performance, a review is pertinent in order to produce a compilation of these studies, providing new elements for athletes and coaches which aim to optimize their performance. Thus, the objective of this work was to present a systematic review of the findings regarding the potential ergogenic effect of food for athletes. Researchers performed a double-blind research in Medline/PubMed considering articles published until January 2019 which resulted in 71 articles. Increased time until exhaustion, improved aerobic capacity and strength recovery were the most commonly reported physical effects. In general, food showed equal or superior ergogenic activity over supplements. Although the number of foods investigated is reasonable, there is still no body of evidence for each studied food, except beets. The current data support the possibility of certain foods being able to enhance athletic performance, as well as serving as an energy source. However, a larger volume of studies is needed to form a body of evidence on each of these foods.

KEYWORDS
Antioxidant; functional foods; athletic performance; exercise training; sports nutrition

Introduction

The search for nutritional resources as an ergogenic tool is evident in sports context (Buell et al. 2013). Sports supplement use has a high prevalence in several populations such as in gyms in New York (84.7%) (Morrison, Frances, and Barbara 2004) and Spain (56.1%) (Goston and Toulson Davisson Correia 2010), and with a range of 32–94% among bodybuilders in Brazil (Nogueira, de Souza, and Brito 2013; Silva et al. 2014). The frequency of supplement use is approximately 41–80% among athletes of different nationalities and sport modalities (Areta et al. 2013; Jung, Lee, and Kim 2013; Tian, Ong, and Tan 2009).

Despite the high and increasing consumption of nutritional supplements, the actual necessity of their use is controversial. Several organizations suggest that physically active individuals do not require additional nutrients, and that supplementation should only be a complement in high-performance athletes or recreational exercise practitioners who are not consuming sufficient energy (American Dietetic Association et al., 2009; Kreider et al. 2010). However, some authors claim that daily food intake is not sufficient to meet the energy requirements of intense sports activities, thus athletes require supplementation (Aljaloud and Ibrahim 2013), and there are a few supplements which evidently promote improved performance and accelerate recovery (Trexler et al. 2015). Other controversial aspects are related to the lack of regulation in the supplement industry, which leaves room for the existence of many products with unknown purity and dubious content (Márquez and Molinero 2009), and reports of adverse effects from the use of various supplements (Stickel et al. 2011).

Alongside these controversies, a new line of research has emerged in recent years which tests the ergogenic potential of fresh foods or processed foods. Most of the products showed isolated ergogenic effects through improvements in oxidative stress and inflammation (Toscano et al. 2015). In other studies, performance improvement (Carvalho-Peixoto et al. 2016), mitigation muscle damage (Connolly et al. 2006) and protein synthesis stimulation (Lunn et al. 2012) have been observed. Furthermore, foods have been compared with supplements in some studies, and most foods produced the same ergogenic effect as supplements.

The growing number of publications in this line of research has already motivated an interesting review study (Naderi et al. 2018), however, these authors only focused on fruits, while other foods such as beets, which has a more robust body of evidence, were not considered. Furthermore, although presenting few studies, several other foods have been shown to be ergogenic, so a review compiling all these possibilities for sports nutrition is pertinent to this current line of research.

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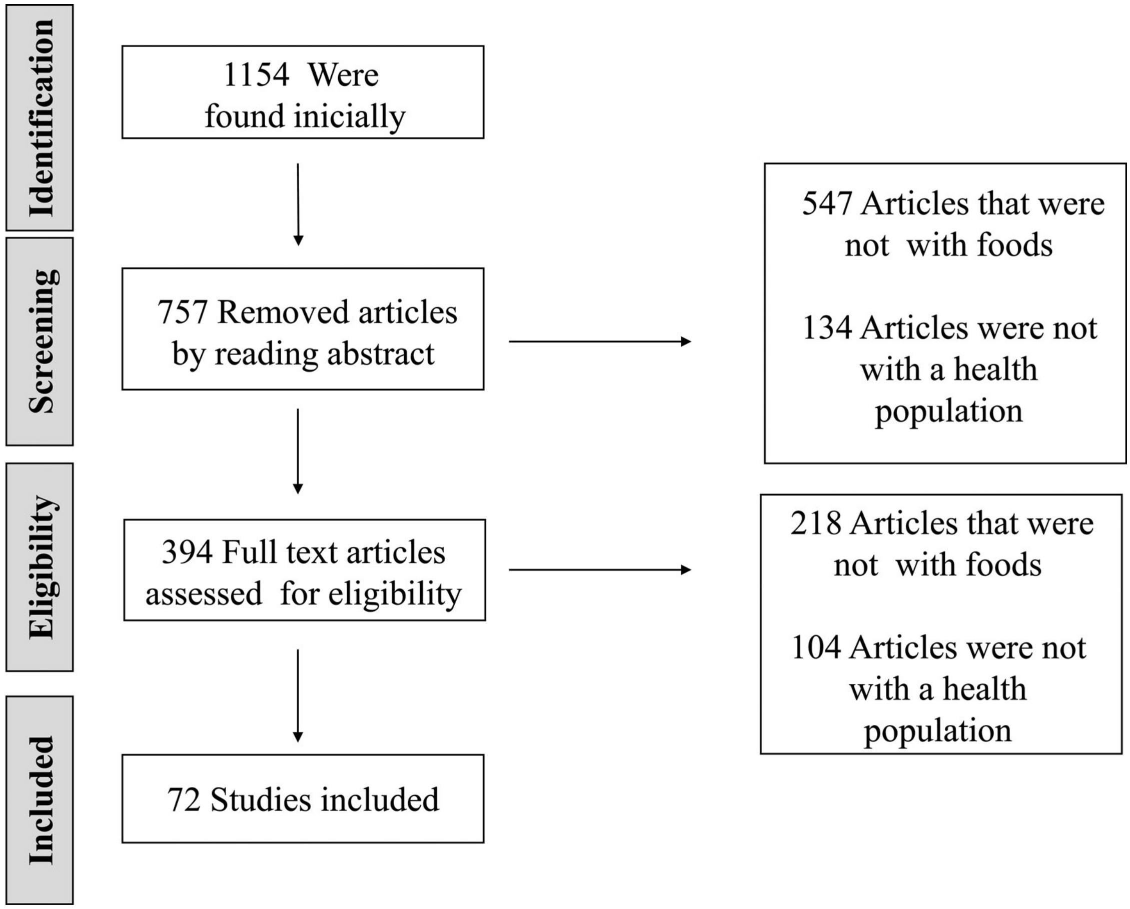

Figure 1. Steps taken to select studies.

Therefore, the objective of this review is to present the results of studies which investigated the ergogenic potential of foods in single doses or interventions over various days/weeks on physical performance, as well as testing the food in comparison with supplements or without this comparison.

Most of the selected studies investigated physical performance (time to exhaustion, oxygen consumption and anaerobic threshold, intermittent exercises), post exercise recovery (recovery and muscle damage, oxidative stress and inflammation). In addition, another category of studies compared foods to nutritional supplements using these previously cited variables.

This article is the first literature review on foods with ergogenic effects. It is hoped to clarify the real ergogenic potential of food and to define which foods have sufficient available evidence to be introduced into the diets of athletes and recreational practitioners.

Methods

Researchers performed a double-blind systematic review of articles in the Medline/PubMed database on foods with ergogenic effects. This article was prepared in accordance with PRISMA. The search strategy was based on PICOS, where the population was athletes. The intervention was supplementation and exercise, with a comparison done pre and post intervention by testing some isolated food, and in other cases the food was tested against some supplement; finally, the outcomes were improvement in performance and the ergogenic effect of foods on the different evaluated parameters. The keywords used to search for the articles were: *athlete AND food* AND *performance* AND *ergogenic* AND *exercise AND sports nutrition*. The respective MeSH terms were used for each keyword. Figure 1 presents the resulting search details. We initially considered all articles published until January 2019, resulting in 1154 publications. The inclusion criteria were studies in English, studies characterized as clinical trials conducted with trained individuals, randomized, and placebo-controlled. Studies that adopted single doses or long-term doses were considered independent of the time intervention. Case reports, literature reviews, abstracts and studies that did not evaluate any ergogenic effects of foods were excluded. Thus, 71 articles met the inclusion criteria for this review.

All studies were subjected to quality assessment based on the PEDro scale. The articles were subdivided into the following topics and were then tabulated and discussed: 1 – foods tested in humans without the use of a supplement as control; 2 – foods compared to commercial supplements.

Results

In total, 1154 articles were found upon the initial search. Exclusion reasons and final articles considered are presented in Figure 1. A total of 71 articles were selected involving 32 foods. They are presented in Tables 2 and 3, ordered by the criterion of the number of studies involving each food. The most studied food was beets (16 studies), followed by chocolate milk (7 studies), cherry juice (6 studies), dark chocolate (3 studies) and bovine colostrum (3 studies). The remaining 36 studies involved 27 different foods.

The studies earned PEDro scores of at least five points. From the 71 articles found, 26 of them (36.6%) scored 5 and 6, while 27 articles (37.5%) scored 7 and 8, and 18 (25,3%) scored from 9 to 11. The classification for each of the articles is demonstrated in the abovementioned tables.

Physical performance

This topic presents studies that evaluated the physical capacity which was adopted as the main outcome of this review, as well as being the gold standard for evaluating the improvement of the sport performance. In this perspective the studies addressed variables such as time to exhaustion, oxygen consumption and anaerobic threshold in the context of intermittent exercises.

Time to exhaustion

The gold standard to demonstrate an ergogenic effect is improvement in physical performance. A way to measure this physical capacity is to use an exercise protocol to exhaustion. This protocol has the advantage of assimilating the competition circumstances. In this view, the effect of food has mainly been tested in cyclical sports (running and cycling). Although swimming is also a cyclical sport, no study was conducted with this modality.

Eleven studies verified the effects of foods on the increase in the time until exhaustion on running and cycling tests. Among these, eight studies (81.8%) confirmed the hypothesis of this ergogenic effect. The foods that delayed fatigue were dark chocolate (Patel, Brouner, and Spendiff 2015), beetroot juice (Muggeridge et al. 2014; Murphy et al. 2012; Wylie et al. 2013), bovine colostrum (Shing et al. 2006), grape juice (Toscano et al. 2015), peppermint essential oil (Meamarbashi and Rajabi 2013) and açai (Carvalho-Peixoto et al. 2016). The foods which were not able to demonstrate increased time to exhaustion were dark chocolate (Allgrove et al. 2011), low fat milk with added cocoa (Peschek et al. 2013), and pistachio nuts (Nieman et al. 2014).

Oxygen consumption and anaerobic threshold

Despite not being a sporting result, anaerobic threshold and aerobic capacity have strong associations with performance in endurance sports (Lundby and Robach 2015). The volume of studies with these two variables is similar to the test protocols until exhaustion and the results are similar, with about 78% of studies indicating improvements in these physiological components.

Nine investigations were selected, in which seven of these studies showed that one of these two variables were improved. The foods studied in this context were dark chocolate (Patel, Brouner, and Spendiff 2015), beetroot (Cermak, Gibala, and van Loon 2012; Kelly et al. 2014; Muggeridge et al. 2014; Wylie et al. 2013), peppermint essential oil (Meamarbashi and Rajabi 2013) and blackcurrant (Elisabeth et al. 2015). The two studies that rejected the hypothesis of improvement in these variables were testing coffee (Demura, Yamada, and Terasawa 2007) and grape juice (O'Connor et al. 2013).

Intermittent exercises

Studies with intermittent exercises have far fewer numbers. There are studies which include strength training (Fulford et al. 2013), cycling (Hoon et al. 2014) and rowing (Bond, Morton, and Braakhuis 2012). Eight studies tested the hypothesis of the ability of foods to promote decreased fatigue in intermittent exercise. This phenomenon was verified in 5 studies with cherries (Connolly, et al. 2006), beetroot (Bond, Morton, and Braakhuis 2012; Fulford et al. 2013; Hoon et al. 2014) and caffeinated chewing-gum (Paton, Lowe, and Irvine 2010). The tested food in the other three studies in which there was no fatigue reduction for this exercise modality was beetroot juice (Hoon et al. 2014; Martin et al. 2014; Puype et al. 2015).

Post exercise recovery

Physical exercise sessions promote acute muscle damage which is usually accompanied by an increase in oxidative stress (Kawamura and Muraoka 2018) and inflammation (Peake et al. 2017). These phenomena together imply in an adaptive response to physical training (Rivera-Brown and Frontera 2012). On the other hand, athletes overtraining present elevated levels of markers related to these variables (Kreher and Schwartz 2012). Meanwhile, researchers have been investigating the effect of food with the potential to attenuate these responses to the exercise, as will be detailed in the following topics.

Recovery and muscle damage

It is characteristic of elite athletes to perform more than seven workouts per week, or two or more workouts per day (Gabbett 2016). Thus, post-exercise recovery becomes an important variable over a season (Kentta, Hassmen, and Raglin 2001). The exercise protocols used to test which foods help in the recovery process are acute and chronic, as well as both strength (Clifford et al. 2016) and endurance exercise (Lunn et al. 2012). This maintenance or improvement in performance is often accompanied by reduced concentrations of damage markers (CK and LDH) and muscle pain, thus corroborating the results of performance tests (Carvalho-Peixoto et al. 2016; Tsitsimpikou et al., 2013).

Six groups of researchers (seven articles) evaluated ergogenic responses related to increased or maintained strength and muscle damage. Positive effects were verified in six studies. The tested foods were cherry juice, in which one of the studies analyzed the participants' responses when submitted to an exercise protocol of 2 sets of 20 repetitions of maximal

Table 1. PICOS criteria for inclusion of studies.

Criterion	Description
Population	Population was athletes and physical activity practitioners
Intervention	Supplementation and exercise
Comparison	It was done pre and post intervention when an isolated food was tested, and in other cases the food was tested against a supplement
Outcomes	Improvement of performance and ergogenic effect of foods in the different evaluated parameters
Study design	Any study in which it examined the potential of a food promoting improvement in parameters related to greater ability to perform exercise

eccentric elbow contractions and found that there was a smaller decrease in strength and reduction in pain sensation in the experimental group during the test (Connolly et al. 2006). Another group of researchers also evaluated the effect of cherry juice intake on subjects who underwent an average 26 km run, and observed a reduction in delay onset of muscle soreness (DOMS) analyzed by visual analog scale (Kuehl et al. 2010). A study using saffron found that 10 days of supplementation (seven days before exercise and three days after) of this compound was able to reduce muscle damage markers (CK and LDH) and maintain strength in an exercise protocol of four sessions with 20 repetitions (Meamarbashi and Rajabi 2015). Another study with this same food showed increased isotonic and isometric force and improvement in audio and visual reaction times (Meamarbashi and Ali 2016). In yet another investigation with this same food, there was a reduction in muscle pain 24 and 48 h after performing an exercise protocol involving seven sets of ten eccentric single-leg extensions (Nicol et al. 2015). A study using beetroot juice showed fatigue attenuation during strenuous exercise with flow restriction (Hoon et al. 2015).

Meanwhile, no effect related to this variable was observed when the ergogenic potential of cherries was tested after eight consecutive days of supplementation (30 ml/2x day), followed by a protocol of maximum voluntary contraction after a 109 min cycling test (Bell et al. 2015).

In the same perspective, seven studies analyzed muscle damage after 24–71 h of exercise. Foods able to attenuate responses in muscle damage parameters were: beetroot (Clifford et al. 2016), fermented milk (Iwasa et al. 2013), watermelon juice (Tarazona-Díaz et al. 2013), and pomegranate, in which the researchers extended the evaluation protocol up to 96 h (Trombold et al. 2010) and 168 h (Trombold et al. 2011). Foods which did not show a positive effect for this same parameter were grape juice (O'Connor et al. 2013) and chocolate milk (Peschek et al. 2013).

Two foods resulted in better performance on a test preceded by a stressful exercise session, indicating acceleration of post-workout recovery; beetroot juice decreased oxygen uptake and improved a 10 km time trial performed immediately after a 60-minute cycling workout (2 × 30 min at 45% and 65% Wmax) (Cermak, Gibala, and van Loon 2012), and chocolate milk increased time to exhaustion in a test performed four hours after two bouts of cycling exercise to exhaustion (Karp et al. 2006).

Oxidative stress and inflammation

Regarding oxidative stress and inflammation, 14 studies tested the antioxidant and anti-inflammatory effect of different foods, and one or more variables were beneficially modified in 10 of them. The foods that promoted reduced oxidative stress were dark chocolate (Allgrove et al. 2011; Davison et al. 2012), cherry juice (Howatson et al. 2010), fermented milk (Iwasa et al. 2013), pequi oil (Miranda-Vilela et al., 2010), tomato (Harms-Ringdahl, Jenssen, and Haghdoost 2012), honey (Tartibian and Maleki 2012), açai (Carvalho-Peixoto et al. 2016), grape juice (Toscano et al. 2015) and ice cream (Sanguigni et al. 2017). Meanwhile, foods which were able to reduce systemic inflammation were cherry juice (Bell et al. 2015; Howatson et al. 2010), honey (Tartibian and Maleki 2012) and grape juice (Toscano et al. 2015). On the other hand, 4 studies denied the hypothesis of protection against oxidative stress and inflammation, including a study using grape juice (O'Connor et al. 2013), lychee extract (Nishizawa et al. 2011), pineapple (Knab et al. 2014) and chia seeds (Nieman et al. 2015).

Foods compared to nutritional supplements

There are studies in which some foods were tested having some supplement as control. There were 16 studies selected in this context. The vast majority of supplements used were electrolytic repositories, isotonic drinks and carbohydrates. The findings are interesting, but limited to a small group of supplements and restricted metabolic effects.

Table 3 presents studies in which the ergogenic effects of foods were compared to commercially available nutritional supplements. Twelve of these studies reported some advantage of foods over the supplements to which they were compared, such as reductions in muscle damage markers with chocolate milk versus a carbohydrate beverage (Gilson et al. 2010), or chocolate milk versus replacement drink versus carbohydrate replenishment drink for time to exhaustion and total work done (Karp et al. 2006), and tomato juice versus a carbohydrate supplement (Tsitsimpikou et al., 2013). Also, increased peak isometric strength performance with blueberries versus a carbohydrate supplement (McLeay et al. 2012) and higher protein synthesis with chocolate milk versus a carbohydrate drink (Lunn et al. 2012) were found.

Other studies showed reduced oxidative stress with a black grape antioxidant drink when compared to carbohydrate-protein (Morillas-Ruiz et al. 2005) and bananas versus a carbohydrate beverage (Nieman et al. 2012). Regarding this, two studies showed improvements in systemic inflammation with tomato juice versus a carbohydrate beverage (Tsitsimpikou et al., 2013), and honey versus a carbohydrate-electrolyte beverage (Abbey and Rankin 2009).

Table 2. Studies on the ergogenic effects of fresh and processed foods in humans.

Author/year	Pedro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
Beetroot: 16 studies							
(Cermak et al., 2012)	9	Crossover Double-blind	13 M trained cyclists or triathletes	Cycling 60 min of submaximal (2×30 min at 45% and 65% Wmax, respectively), followed by a 10-km time trial.	Beetroot concentrated juice 140 ml/d (~8 mmol/d nitrate) every morning after breakfast for 6 days before testing	Blood Pressure Cardiorespiratory Data, Ratings of perceived exertion, Plasma NO3, glucose, insulin, lactate, free-fatty-acid concentrations Time-Trial Performance	↓ Submaximal VO2 ↑ NO3 ↑ free-fatty-acid concentration ↓Time-Trial Performance ↑Power output No differences for other evaluated variables
(Murphy et al. 2012)	11	Crossover Placebo-Controlled Double-blind	5 M and 6 F healthy untrained	Two sessions of 5 km in the treadmill	Beet (200 g with content $\geq$ 500 mg of nitrate) 75 min before exercise	Vm, BP, HR, SPE	Trend toward ↑ mean Vm 5%, ↑ in Vm in the last 1.8 km, ↓ SPE No differences for other evaluated variables
(H. Bond, Morton, and Braakhuis 2012)	10	Crossover Randomized Placebo-Controlled	14 M well-trained junior rowers	Rowing-ergometer repetitions 6×500- at maximal intensity, recovery period of 90 s between repetitions	Beetroot (5.5 mmol/day of NO3 each day (250 ml in the morning, 250 ml in the afternoon) daily for 6 d	Blood pressure, oxygen saturation, maximum heart rate, urine (specific gravity, pH, and nitrites), and lactates, performance test	Improvement in maximal repeated 6 500-m rowing-ergometer bouts No differences for other evaluated variables
(Fulford et al. 2013)	9	Crossover Randomized Placebo-Controlled Double-blind	8 M healthy physically active males	MVCs 50 at 2.5 h, 5 days and 15 days after the beginning of the supplementation period	Nitrate-rich consumed 0.25 l of beetroot juice twice a day, once in the morning and once in the evening 0.5 l/day of beetroot juice for 15 days	Plasma nitrite concentration, Muscle force, phosphodiester, PCr, α-ATP, γ-ATP and β-ATP, pH, Force data, Muscle force	↑ Plasma [NO2], ↓ PCr cost per unit force output, No differences for other evaluated variables
(Wylie et al. 2013)	10	Crossover Randomized Placebo-Controlled Double-blind	10 M healthy recreationally active	Cycle exercise tests at moderate-intensity and severe-intensity	Beetroot NO3 rich – 70, 140, or 280 ml, 2,5 h before exercise	Plasma nitrite and nitrate systolic and diastolic BP and MAP, time-to-task failure	↑ plasma NO3 and NO2 ↓ SPB and MAP ↓ steady-state oxygen (O2) ↑ time-to-task failure
(Hoon et al. 2014)	5	Crossover Randomized Placebo-Controlled	26 M cyclists high-intensit performance task in national-level cyclists	Cycling time trials 2 bouts of 4 min	Nitrate-rich beetroot juice of 70 mL at 150 min or 75 min before the first time trial, addition of a 35 mL "top-up dose" following the first time trial in the 150 min condition	Plasma [NO2], cycling performance	↑ Plasma [NO2 No differences for other evaluated variables
(Muggeridge et al. 2014)	5	Crossover Randomized Placebo-Controlled Double-blind	9 M trained cyclists	Cycle ergometer (1 initial progressive test until exhaustion + 3 hypoxic performance tests of 15 min at 60% of HR max)	Beet juice (single dose of 70 mL – 5 mmol of nitrate- 3 h before the second and third performance tests)	Plasma nitrate and nitrite, BP, VO_2 peak and maximum, SpO_2 and performance	↑ Nitrate and nitrite, ↓ VO_2, Better time trial 2.9% in the altitude endurance exercise
(Puype et al. 2015)	7	Randomized Controlled Single-blind	22 M healthy, subjects, aged 18–30 years	Cycling (3 min at 70%, 3 min at 80%, and eventually 3 min at 90% of the training workload)	Beetroot pretest and the post-test, the full daily dose of either	Power output, NO3, VO2max, Muscle phospho-AMP-activated protein kinase, Muscle	No effects of intermittent hypoxic training on endurance exercise

(*continued*)

Table 2. Continued.

Author/year	Pedro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
					(0.07 mmol NO3 −/kg bw, ∼500 mL)	glycogen, hypoxia inducible factor-1α mRNA content, TT	
(Kelly et al. 2014)	9	Crossover Randomized Placebo-Controlled Double blind	12 M physically active subjects	Cycling incremental test: 3 min at 20 W and 80 rpm, increased at a rate of 30 W/min	Rich beetroot juice (8.4 mmol NO3) 140 ml/day	Pulmonary gas exchange and ventilation, (NO2), oxygen uptake (VO2) kinetics, exercise tolerance in normoxia (N) and hypoxia (H)	↑ NO2, ↓ the O2 cost of Submaximal cycle exercise in hypoxia, ↓ in steady-state VO2, enhances VO2 kinetics during moderate-intensity exercise and improves severe-intensity exercise tolerance
(Martin et al., 2014)	8	Crossover Randomized Placebo-Controlled Double-blind	16 Team-sport athletes (9 M and 7 F)	2-minute warm-up, cycling at 100 W, repeated 8-second bouts of high-intensity exercise	Beetroot juice 70 mL containing a minimum of 0.3 g of nitrate (NT) or 70 mL 2 h before a repeated-sprint protocol	HIIST Performance, VO2 and Heart Rate, Plasma Lactate and Rating of Perceived Exertion.	Dietary nitrate is not beneficial for improving repeated-sprint performance
(Bond et al. 2014)	7	Crossover Randomized Controlled	12 F healthy, young adult physically active	Leg cycle ergometer level of 20 W for 3 min and was increased by equal work intensities every 3 min to volitional fatigue	Beetroot juice of 500 mL before exercise	Plasma NO concentration, VO2, heart rate-SBP product at rest and at the constant exercise workloads, carbon dioxide excretion rate, respiratory exchange quotient	↑ plasma NO concentration, ↓ oxygen consumption, ↓SBP and heart rate-SBP product at rest and at 40%, 60%, and 80% of peak oxygen consumption, No differences for other evaluated variables
(Thompson et al. 2015)	10	Crossover Randomized Placebo-Controlled Double-blind	16 M team-sport players	intermittent-sprint exercise two 36-min "halves"	Beetroot juice; ∼6.4 mmol of NO3− per 70 mL morning and evening for 6 days / On day 7 consumed 2 × 70 mL of and did test 2.5 h later	Plasma NO2 and NO3 Total work done, Pulmonary gas exchange and heart rate, blood lactate, blood glucose cognitive assessment,	↑ NO2 and NO3 ↑ total work done, attenuate the ↓ in decision-making reaction time, No differences for other evaluated variables
(Hoon et al. 2015)	10	Crossover Randomized Placebo-Controlled Double-blind	19 adults (M 13, F 6)	Isometric knee extension force, muscular fatigue examined in 2 separate continuous stimulation fatigue tests, with and without blood flow restriction.	Nitrate; days 1–3: 525 mg NO− 3, day 4: 1050 mg NO − 3	Muscle function testing, Force frequency, Maximum voluntary contraction, Fatigue tests	↓ decline in the % of initial force No differences for other evaluated variables
(Clifford et al. 2016)	10	Double-blind Placebo-Controlled	30 M recreational active	100- drop jumps from a 0.6 m high steel box; each jump was separated by a 10 s interval and each 20 jumps by a 2 min rest period (i.e. 5 sets of 20 repetitions).	Beetroot juice (H-BT; 250 ml), or a lower dose of beetroot juice (L-BT; 125 ml)	Maximal isometric voluntary contractions, countermovement jumps (CMJ), pressure pain threshold, (CK), (IL-6), (IL-8) and (TNF-α)	CMJ performance recovered quicker at 48 and 72 h, PPT greater at 24h No differences for other evaluated variables

(Cristhian F. Montenegro et al. 2017)	8	Crossover Randomized Placebo-Controlled Double-blind	Twenty-two (9 M and 13 F) triathletes (age, 38 ± 11 years)	40 min of cycling (75 ± 5 % maximal oxygen consumption) followed by a 10-km running time trial. 24 h later a 5-km running TT was done	Betalain-rich concentrate of beetroots (50 mg) by 6 days of supplementation with 100 mg•day − 1, 120 min before exercise protocol	Ratings of perceived exertion, CK, 10-km TT, 5-km TT	↓ increase of CK, 10 kilometer TT duration was faster with the BRC, 5 kilometer TT duration 24 h after the 10-km TT was faster in 17 of the 22 subjects with the treatment
(Porcelli et al. 2016)	7	Crossover Randomized Controlled	7 M healthy subjects	Moderate intensity constant-work rate cycling exercise, Isometric knee extensions, Repeated Sprint Ability test	Diet with a high nitrate intake. Diets were isoenergetic (about 2200 kcal) for six days	Pulmonary ventilation O2, and carbon dioxide output Heart rate, Force recording,	↓ oxygen consumption during moderate-intensity, constant work-rate cycling exercise, ↑ total muscle work during fatiguing, intermittent, sub-maximal isometric knee extension, improved performance in Repeated Sprint Ability test
Cherry juice: 06 studies							
(Connolly et al., 2006)	5	Crossover Randomized Placebo-Controlled	14 M college students	Eccentric elbow flexion contractions (2 × 20 maximum contractions)	Cherry juice blend 350 ml 2x/day for 8 consecutive days	Strength loss, pain Measurement of isometric elbow flexion strength, muscle tenderness	↓ Strength loss and pain No differences for other evaluated variables
(Howatson et al. 2010)	6	Pseudo-Randomized Placebo-Controlled	13 M and 7 F recreational marathon runners	Race under conditions similar to the 2008 London Marathon	Cherry juice (237 mL, 2x/day for 8 days before, immediately after, 24 h and 48 h after the race)	Muscle damage (CK, LDH, muscle pain and isometric contraction, Inflammation (IL-6, CRP and uric acid) Oxidative stress (TAS; TBARS and protein catabolism)	↓ inflammation (IL-6, CRP, uric acid), Isometric strength recovered more quickly, ↑ TAS in 10% and ↓ TBARS after 48 h, No differences for other evaluated variables
(Kuehl et al. 2010)	8	Randomized Placebo-Controlled Double-blind	36 M and 18 F healthy runners	Long distance relay race (total mean distance of 26.3 ± 2.5 km/participant)	Cherry juice (355 mL, 2x/day for 8 days, 7 days before and during the race)	VAS, where 0 mm is "no pain", 100 mm is "more severe pain"; Questionnaire of satisfaction with pain relief	↓ muscle pain induced by strenuous exercise, ↑ satisfaction with pain reduction
(Bell et al. 2015)	8	Placebo-Controlled Double-blind	16 M Trained cyclists	Cycling trial 109-min designed to replicate road race demands	Cherries juice Montmorency tart 30 mL 2x/ day for 8 consecutive days	Maximum voluntary isometric contraction, inflammation (interleukin IL-1, IL-6, IL-8, tumor necrosis factor alpha, high-sensitivity C-reactive protein (hsCRP)), oxidative stress (lipid hydroperoxides),	↓ IL-6, ↓ hsCRP No differences for other evaluated variables

(continued)

Table 2. Continued.

Author/year	Pedro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
						muscle damage (creatine kinase)	
(McCormick et al. 2016)	10	Crossover Randomized Placebo-Controlled Double-blind	9 M Water Polo athletes	In-water vertical jump test, 10 m sprint test, repeat sprint test and the Water Polo Intermittent Shuttle Test (WIST) [8	Tart Montmorency 90 mL daily or a PLA equivalent for a total of 6 days. Two doses each day; before morning training, and in the evening post training.	Interleukin-6 (IL-6); C-reactive protein (CRP)] and oxidative stress (Uric Acid; F2-Isoprostane; total quality of recovery, delayed onset muscle soreness	No differences for the other evaluated variables
(Levers et al. 2016)	8	Randomized Placebo-Controlled Double-blind	27 participants M (n =18) and F (n = 9) endurance-trained runners or triathletes.	Half-marathon (21.1 km) run	Powdered tart cherries (TC, n = 11) or rice flour placebo 480 mg (P, n = 16). supplemented one time daily (480 mg/day) for 10-d	Muscle soreness, cortisol, testosterone, SOD, TAC, MDA, IL-1β, IL-2, IL-4, IL-5, IL-6, IL-7, IL-8, IL-10, IL-12p70, IL-13, TNF-α, IFN-γ, granulocyte-macrophage colony-stimulating factor	Faster race finish, attenuations in muscle catabolic markers over time for (creatinine, urea/blood urea nitrogen, total protein, and cortisol), ↑ antioxidant activity at 24 and 48-h, ↓ Inflammatory markers,
Dark chocolate: 03 studies							
(Allgrove et al. 2011)	6	Crossover Randomized Controlled	20 M active, familiar with cycling	Cycling at 60% of VO_2 max for 1.5 h, with the intensity increased to 90% of VO_2 max, for a period of 30 s every 10 min until exhaustion	Dark chocolate (40 g 2x/day, 2 h before exercise, for 2 weeks)	F2-isoprostanes, oxidized LDL, FFA, glucose, insulin, glucagon, cortisol, interleukin (post-exhaustion and after 1 h of recovery) and time to exhaustion	↓ F2-isoprostanes at exhaustion and after 1 h of recovery ↓ oxidized LDL 21% ↑ FFA during exercise No differences for other evaluated variables
(Davison et al. 2012)	5	Randomized Controlled Single-blind	14 M healthy	Cycling at 60% of VO2 max for 2.5 h	Dark chocolate (single dose of 100 g before exercise)	VO_2 max, HR, glucose, F2-isoprostane, polyphenols, plasma insulin and cortisol, Vit C, TAS, IL-6, neutrophilia, leukocytosis magnitude and changes in the function of neutrophils	Better maintenance of glucose that ↓ post-exercise and ↑ 1 h post-exercise ↑ antioxidant status and ↓ F2-isoprostane, ↑ insulin No differences for other evaluated variables
(Patelet al., 2015)	6	Crossover Randomized Controlled	9 M moderately trained	Cycle test 20-min at 80 % GET and all out sprint performance	Dark chocolate or white chocolate 40 g for 14 day	VO2max test, gas exchange threshold (GET), Blood lactate, Heart rate, Blood pressure, distance time trial	↑ Work rate achieved at GET by 11 % compared to White Chocolate and 21 % compared to baseline, ↑ total distance covered of 17 % No differences for other evaluated variables
Bovine colostrum: 03 studies							
(Shing et al. 2006)	10					TT, VO2max test	

		Placebo-controlled Double blind	29 M highly trained road cyclists	Time to fatigue test at 110% of ventilatory threshold, and a 40 km time trial	Bovine colostrum protein concentrated 10 g/day for 5 weeks		↑ TT, prevented ↓ in ventilatory threshold
(Marchbank et al., 2010)	8	Crossover Double-blind	12 M healthy subjects regular exercisers and took part in running	Treadmill, with 1% grade, for 20 min at a constant speed equivalent to 80% V ˙O2max	Bovine colostrum 20 g/day daily for 14 days before the main exercise trials	VO_2max, Hemoglobin, hematocrit, lactate, glucose, VIP, PYY, ghrelin, GLP-1, Intestinal permeability, (active caspase-3 and 9, Bax_, Bcl-2), (HSP70) expression and epithelial electrical resistance.	↑ HSP70, ↓ temperature, ↓ Intestinal permeability, ↑ Baxα and ↓ in Bcl-2 was partially reversed No differences for other evaluated variables
(Morrison, Cheung, & Cotter, 2004)	7	Crossover Placebo-Controlled Double-blind	15 M participants n = 7 trained and n = 8 untrained completed all experimental trials	Cycling 15-min at initially eliciting 50%, before running for 30 min at a fixed speed 80% HRR (run 1), 30-min running maximal distance trial	Bovine colostrum 1.7 g•kg − 1•day − 1 for 7 days before test	Hemoglobin, hematocrit, core and skin temperature, Hydration status and plasma volume, Heart rate, blood pressure, esophageal, Gastrointestinal permeability and blood, I-FABP	No benefit on the physiology or performance of either highly trained endurance athletes or untrained individuals
Curcumin: 03 studies							
(Nicol et al. 2015)	9	Crossover Randomized Controlled Double-blind	19 M healthy light to moderate regular physical activity	Eccentric single-leg press 7 sets of ten repetitions and then single-leg jump performance	Curcumin capsules containing 2.5 g twice daily for 2.5 days prior to exercise, then 5 capsules twice daily for 2.5 days after exercise	Muscle pain, muscle swelling, single-leg jump height, CK, IL-6, TNF-alpha	↓ pain 24 h and 48h after, minimized the loss of strength in the exercises, ↓ in creatine kinase activity by 29% No difference for other variables variables evaluated
(Meamarbashi and Rajabi 2015)	6	Randomized Placebo-Controlled Double-blind	39 M nonactive	4 sets of eccentric exercise on a leg press machine. The weight load was set to 80% maximum isotonic force in 4 sets	Saffron dried 1 capsule containing 300 mg/d 1 week before and 3 days after eccentric exercise	CK and LDH, maximum isometric and isotonic forces, pain	No ↓ in maximum isometric and isotonic forces ↓ CK and LDH ↓ pain
(Meamarbashi and Ali 2016)	9	Randomized Placebo-controlled Double-blind	28 young healthy M nonactive university students	10-minute warmup following by maximum isometric force in a leg press machine	Saffron (300 mg/day for 10 days)	Isometric force, isotonic force, reaction times	↑ Isometric force, ↑ Isotonic force, faster visual and audio reaction times
	Chocolate milk: 02 studies						
(Peschek et al. 2013)	8	Crossover Randomized Controlled Single-blind	8 M endurance athletes	Race until exhaustion at 70% of VO_2max, performance of a 5 km race after 48 h	Chocolate milk (240 mL – 350 mg of flavonoids-1 g of CHO/kg of body weight, immediately after the race and 2 h after)	Muscle soreness, CK and time to exhaustion	No differences for the evaluated variables
(Papacosta, Nassis, and Gleeson 2015)	5	Crossover Controlled	12 M trained judo athletes	5 days of intensive judo training followed by a simulated judo competition, on 2 separate training weeks 14 days apart	Chocolate milk 1000 mL immediately post-training	Salivary cortisol and testosterone, salivary secretory immunoglobulin A, delayed-onset muscle soreness (DOMS), and	↓ salivary cortisol, ↓ total mood disturbance scores, ↑ number of pushups, ↑ SJFT performance index

(continued)

Table 2. Continued.

Author/year	Pedro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
						judo-related performance	
Pomenagrate: 02 studies							
(Trombold et al. 2010)	8	Crossover Randomized Placebo-Controlled	16 M Recreationally active	Eccentric elbow flexion two sets of 20 maximal repetitions starting with the elbow at 50- of full flexion and ending at 170°	Pomenagrate extract (500 mL) 2x/day at 12-h intervals during each 9-d testing period	Maximal isometric elbow flexion strength, muscle soreness, creatine kinase, myoglobin,interleukin 6, C-reactive protein	↑ strength, delayed-onset muscle soreness No differences for other evaluated variables
(Trombold et al. 2011)	9	Crossover Placebo-Controlled Double-blind	17 M healthy physically active, resistance trained	Weight training at least 2 sets of elbow flexion and knee extension at an intensity of 70–90%	Pomegranate Juice (250 ml) were ingested 2/day daily at 12-hour intervals over each 15-daytreatment	Maximal eccentric elbow flexion, Maximal isometric elbow flexion strength and muscle soreness	Attenuated ↓ the reduction in isometric strength of the elbow flexor muscles, ↓ muscle soreness No differences for other evaluated variables
Grape juice: 02 studies							
(O'Connor et al. 2013)	10	Randomized Placebo-Controlled Single-blind	40 active M and F	Treadmill-running and High intensity eccentric force (18 repetitions) in the non-dominant elbow flexors	Grape juice (46 g grape extract diluted in 236.6 mL distilled water for 45 days)	VO_2max, mood, health condition, inflammation and muscle pain	No differences for all variables
(Toscano et al. 2015)	7	Randomized Controlled	28 runners both genders (22 M and 6 F)trained and participate in an amateur run	Time-to exhaustion exercise test, anaerobic threshold test and aerobic capacity test	Purple grape juice 10 mL/kg/day divided in doses prior to and immediately after training for 28 days	Anaerobic threshold, aerobic capacity and time-to exhaustion, vitamins A and E, uric acid, leukocytes, monocytes, lymphocytes, neutrophils, (MDA), (TBARS), (TAC), (hsCRP), (AGP), (CK), (LDH)	↑ Significant in running time-to-exhaustion, ↑ vitamin A, ↑ uric acid, ↑ total antioxidant capacity, ↓ AGP No differences for other evaluated variables.
Coffee: 02 studies							
(Demura, Yamada, and Terasawa 2007)	5	Crossover Single-blind	10 M healthy	Cycling: 60% of VO_2 max for 60 min	Coffee (6 mg/kg of caffeine 60 min before exercise)	VO_2 peak, anaerobic threshold, HR, SPE, lactate	↓ SPE No differences for other evaluated variables
(Paton, Lowe, and Irvine 2010)	8	Crossover Placebo-Controlled Double blind	9 M well-trained cyclists	4 exercises sets each of 5 min duration. five 30-s maximal effort sprints separated with 30-s active recovery	Caffeinated chewing-gum 6 pieces (240 mg), Immediately following the second exercise set	(VO2max), peak power output, Testosterone, cortisol, power output	↑Testosterone ↓cortisol ↓Fatigue No differences for other evaluated variables
	Tomato: 01 study						
(Harms-Ringdahl, Jenssen, and Haghdoost 2012)	5	Crossover Controlled	15 Untrained M and F	Cycle ergometer for 20 minutes at 80% of HRmax	Tomato juice (- 0.1 mg of lycopene/mL) (150 mL/day for two periods of 5 weeks)	Oxidative stress: 8-oxodG	Protected the ↑ ROS and ↓ 8-oxodG
	Peppermint essential oil: 01 study						
(Abbas Meamarbashi and Ali Rajabi, 2013)	5	Randomized Placebo-Double-blind	12 M exercise practitioners	Incremental test (Bruce protocol)	Peppermint essential oil (0.05 mL diluted in	Respiratory capacity, time to exhaustion and lactate	↑ respiratory ventilation, ↑ respiratory rate, ↑VO2/Kg, ↑ VCO2/Kg, ↑

					500 mL of water/day for 10 days)		MET,↑ energy expenditure , ↑ 24,9% time to exhaustion and 10% VO2 peak, ↓ lactate production
Pequi oil: 01 study]							
(Miranda-Vilela et al., 2010)	5	Randomized Controlled	75 M and 49 F runners	Running between 4 km and 21 km according to the weekly training load	Pequi oil (400 mg/day for14 days)	TBARS, Genotypes of antioxidant enzymes: MnSOD (-Val9Ala), CAT (-21A/T) and GPx1 (Pro198 Leu)	↓ TBARS ↓ oxidative DNA damage No differences for other evaluated variables
Lychee extract: 01 study							
(Nishizawa et al. 2011)	7	Randomized Placebo-Controlled Double-blind	20 M long distance runners (9 were elite athletes)	High-intensity racing (800-1000 km for 2 months)	Lychee extract (50 mg + 150 mg dextrin 2x/day for 2 months)	HR, TGF-β, IL-6, IL-10, cortisol, antioxidant capacity of the oxygen radical, nitrite, LDH, CPK, CRP, hematological parameters	↓ HR, ↑ TGF-β, ↓ IL-6 and ↓ white blood cell count No differences for other evaluated variables
Cashew juice: 01 study							
(Prasertsri et al. 2013)	9	Crossover Randomized Placebo -Controlled	10 trained M and 10 untrained M	Cycling for 20 minutes at 85% of VO_2max	Cashew juice (3.5 mL/kg of body weight/day for 4 weeks)	Plasma Vit C , Lipid and glycemic profile, Oxidation of fat and carbohydrates	↑ [Vit C] in trained (higher value) and untrained ↑ fat oxidation in trained (higher value) and untrained ↓ CHO oxidation unchanged regarding training No differences for other evaluated variables
Natural watermelon juice: 01 study							
(Tarazona-Díaz et al. 2013)	5	Randomized Placebo -Controlled	7 M practitioners of different sports	Maximal exercise test on a cycle ergometer	Natural watermelon juice (500 mL − 1.17 g of L-citrulline) and watermelon juice enriched with L-citrulline (4.83 g) 1h before the test	HR, BP, SPE, Muscle pain (1 − 5 scale), Blood lactate	Both juices helped ↓ the recovery HR and ↓ muscle pain after 24 h No differences for other evaluated variables
Honey: 01 study							
(Tartibian and Maleki 2012)	7	Randomized Double-blind	39 M long distance cyclists	8 weeks of intensity training	Honey (70 g + 250 mL of water for 8 weeks)	Analyses of cytokines (IL-1b, IL-6, IL-8, TNF-α) and oxidative stress (ROS, MDA, SOD, CAT and TAC) in semen	↓ IL-1b, IL-6, IL-8, TNF-α, ROS and MDA ↑ SOD, CAT and TAC
Kefir: 01 study							
(O'Brien et al. 2015)	6	Single-blind Controlled	67 healthy participants Adult M and F aged 18 to 24 yr	15 weeks endurance training, 2x/ weekly	Kefir beverage that was consumed 2x/ week 30 min after each training session	Body composition, C-reactive protein	↓ CRP No differences for other evaluated variables
Açaí: 01 study							
	7						

(*continued*)

Table 2. Continued.

Author/year	Pedro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
(Carvalho-Peixoto et al. 2016)		Randomized Controlled Single-blind	14 M athletes (aeronautic pentathlons, runners and sprinters)	3 exercise tests: 45 a ramp-incremental maximal exercise test and 2 maximal exercise bouts at 90% vo2max	Acai 300 ml immediately after exercise, for 3 consecutive days and one hour before the exercise bout to exhaustion	AST, ALT, LDH, CK, MDA, GPx, Ammonia, Urate, urea, Creatinine, ratings of perceived, time to exhaustion, HR VO2, VCO2, VE, lymphocytes	↓ ALT, ↓AST, ↓LDH, ↓ MDA, ↓GPx, ↓ blood creatinine, ↓RPE, ↑ time to exhaustion, ↓HR, , ↓lymphocytes No differences for other evaluated variables
Pistachio nuts: 01 study							
(Nieman et al. 2014)	6	Randomized Controlled Double-blind	19 M cyclists Regularly competed in road races	Two 75-km cycling time trials	Pistachio nuts (85 g) daily	Complete blood counts, F2-isoprostanes, (CRP), (MCP-1), (TNFa), (GCSF), IL-6, IL-8, and IL-10, Granulocyte Phagocytosis (GPHAG), Oxidative Burst Activity (GOBA)	Performance time for the 75-km time trial was 4.8% slower under pistachio conditions
Juice powder mixed: 01 study							
(Knab et al. 2014)	6	Randomized Controlled	34 trained endurance cyclists (25 M, 9 F)	Cycled at 70%–75% VO2max for 2.25 h per day, followed by a 15-min time trial.	Juice powder mixed in 177 mL (6 fluid ounces) of pineapple juice) in the morning and again at lunch time (for a total of 473 mL	IL-6, IL-8; TNF; (MCP-1), (ORAC), (FRAP), and oxidized glutathione, protein carbonyls, and innate immune function (M-PHAG) phagocytosis and oxidative burst activity)	No exercise-induced alterations in inflammation and oxidative stress or immune function in trained cyclists
Chia seed: 01 study							
(Nieman et al. 2015)	7	Crossover Randomized Controlled	24 participants M (n = 16) and F (n = 8) runners	Treadmills at 70% VO2max to exhaustion	Chia seed oil 0.5 liters water with 7 kcal. kg /30 min before treadmill running to exhaustion	Oxygen consumption, ventilation, (RPE), plasma glucose, blood lactate, total leukocyte counts, plasma cortisol, (IL-6), (IL-8), (IL-10), (TNF-α).	No additional recovery benefits
Cocoa: 01 study							
(Peschek et al. 2013)	7	Crossover Randomized Controlled Single-blind	8 M Well-trained runners and triathletes	Treadmill declined to a −10% grade and the speed adjusted to 70% of VO2max	Cocoa CHOC: 350 mg flavanols per serving) immediately after the downhill run and again 2 h later	CK, muscles soreness	No additional recovery benefits
Blackcurrant: 01 study							
(Elisabeth et al. 2015)	8	Crossover Randomized Placebo-Controlled Double-blind	13 trained triathletes M (n = 8) and F (n = 5)	Cycling protocol of 4 min stages with 2 min recovery, start power 50 W with 30 W increments	Blackcurrant powder (6g/ day) take with breakfast	Plasma lactate, Maximum Oxygen Uptake, Cardiovascular Function in Rest, Cardiovascular Responses During Exercise, OBLA,	↓ Plasma lactate, ↑ stroke volume and cardiac output, ↓ total peripheral resistance, ↑ OBLA No differences for other variables variables evaluated
Fermented milk: 01 study							
(Iwasa et al. 2013)	8					Oxygen consumption and carbon dioxide	↑ carbohydrate oxidative capacity,

		Crossover Randomized Placebo-Controlled Double blind	18 M healthy young not habituated to a regular exercise	bicycle ergometer for 5 min and resistance exercise for 45 min	Fermented milk 3x200 mL; 1 before and 2 after test	production, LDL, HDL, total cholesterol), free fatty acid, hsCRP, TNF-α CPK, ORAC, 8-OHdG, blood lactate, glucose	↓ creatine phosphokinase, ↓ Muscle soreness No differences for other evaluated variables
Ice cream: 01 study							
(Sanguigni et al. 2017)	8	Crossover Single-blind	14 M healthy individuals n = 7 and F n = 7	Cycle ergometer with a scalar profile and increasing loads of 25 watts/2 min	Ice cream 100g containing dark cocoa powder and hazelnut and green tea extracts or milk chocolate ice cream (control ice cream). g 2 h before exercise protocol	Serum polyphenols, antioxidant status (ferric-reducing ability of plasma [FRAP], (NOx) [d-ROMs], [H2O2], [FMD [RHI], and exercise tolerance (stress test)	↑ Serum polyphenols, improved FRAP and FMD, ↑ RHI , ↓ oxidative stress No differences for other evaluated variables

Legend: ↑: statistically significant increase; ↓: statistically significant decrease; AST: aspartate aminotransferase; ALT: alanine aminotransferase; AKT: Protein Kinase B; BP: blood pressure; CHO: carbohydrates; CK: creatine kinase; CRP: C-reactive protein; CAT: catalase; CPK: creatine phosphokinase; DNA: deoxyribonucleic acid; DHA: docosahexaenoic acid; EPA: eicosapentaenoic acid; FFA: free fatty acids; F: female; %F: percentage of fat; FOXO3: Forkhead box O3; GPx: glutathione peroxidase; HDL-c: high density lipoprotein cholesterol; HR: heart rate; IFN-γ: interferon gamma; IL: interleukin; IF4E-BP1: Eukaryotic translation initiation factor 4E-binding protein 1; LDL-c: low density lipoprotein cholesterol; LDH: lactate dehydrogenase; M: male; NK: natural killer; 8-OHdG: 8-hydroxy-2′-deoxyguanosine; PBMC: peripheral blood mononuclear cells; ROS: reactive oxygen species; SpO2: peripheral oxygen saturation;SOD: superoxide dismutase; SPE: subjective perception of exertion; TG: triglycerides; TAS: total antioxidant status; TBARS: thiobarbituric acid reactive substances; TGF-β: Transforming growth factor beta; TNF-α: tumor necrosis factor alpha; TAC: total antioxidant capacity; VAS: visual analogue scale; Vm: mean velocity.

Table 3. Studies on the use of ergogenic foods compared to commercial supplements.

Author/Year	PEDro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
(Karp et al. 2006)	8	Crossover Randomized Controlled Single-blind	9 M trained cyclists	Cycling to exhaustion interval workout followed by 4 h of recovery, and a subsequent endurance trial to exhaustion at 70%	Chocolate milk (509.1 mL in the IPT and 2 h after training) *versus* Electrolyte drink *versus* Commercial supplement (CHO + PRO + antioxidants) (isovolumetric)	Time to exhaustion, total work performed, average heart rate, blood Lactate, PSE, total work	↑ Time to Exhaustion ↑ work performed
(Pritchett et al. 2009)	6	Crossover Randomized Controlled	10 M recreational cyclists	Cycling at 85% of VO_2 max until exhaustion	Chocolate milk (531 mL/day containing 1.0 g of CHO/kg IPT and 2 h after exercise for one week) *versus* commercial supplement (CHO + PRO + antioxidants) (isocaloric, isoglycidic and isoproteic)	CK, SPE, daytime sleepiness scale and time to exhaustion	No differences between treatments for the evaluated variables
(Thomas, Morris, and Stevenson 2009)	6	Crossover Randomized Controlled	9 M trained	Cycle to exhaustion at 70% p max	Chocolate milk 450 ml at 0 and 2 of recovery period ***versus*** carbohydrate replacement drink or fluid replacement drink	Endurance capacity trial, Time to exhaustion	↑ Endurance capacity trial ↑ Time to exhaustion
(Gilson et al. 2010)	7	Crossover Randomized Controlled Double-blind	13 M soccer players	Usual training for one week, followed by four days of increase in training time duration	**Chocolate milk (672 mL in the four days of increased training)** *versus* Supplement with high CHO content (isovolumetric and isocaloric)	CK, Mb, muscle pain, fatigue, MVC, performance tests	Increase in CK attenuated with chocolate milk No differences in Mb, muscle pain, fatigue and MVC ↑ Mean daily training time and HR for both treatments No differences in the performance tests
(Lunn et al. 2012)	6	Crossover Randomized Controlled	14 M runners	Running on a treadmill for 45 min after reaching 65% VO_2max and three hours after running until exhaustion	Chocolate milk (single dose of 480 mL after a 45 min run) ***versus*** or a no nitrogenous isocaloric carbohydrate	Muscle protein synthesis, body protein turnover, protein phosphorylation, activity of translational proteolytic signaling molecules, muscle glycogen, time to exhaustion	↑ protein synthesis ↓ proteolysis ↑ phosphorylation of eIF4E-BP1 and FOXO3, ↓ phosphorylation of Akt, ↓ activity of caspase 3, ↑ 23% time to exhaustion
(Samaras et al., 2014)	5	Controlled	43 M and F ultramarathon runners	Monitoring without changing the training program	Tomato juice (during and after exercise sessions for two months) ***versus*** Protein bar (1CHO:1PTN)	glucose, total cholesterol, TG, LDL, HDL, TAC, GSH, TBARS, protein carbonylation and FMD	↑ FMD, ↓ glucose, ↓ cholesterol, ↓ LDL ↓ TBARS and ↓ protein carbonylation for tomato juice

					versus Usual carbohydrate drink		↑ GSH, ↓ TBARS, ↓ protein carbonylation and ↑ LDL for the protein bar No changes in the control group
(Tsitsimpikou et al., 2013)	7	Randomized Controlled	4 F and 11 M anaerobically trained athletes with high baseline levels of CK and LDH	Usual anaerobic exercise	Tomato juice (100 g during and after exercise for 2 months) *versus* Usual carbohydrates drink	LDH, CK, CRP and homocysteine	↓ LDH, ↓ CK, ↓ CRP and ↓ homocysteine for tomato juice No changes in the control group
(Saat et al. 2002)	5	Crossover Randomized Controlled	8 M recreational exercise practitioners	Treadmill at 60% VO2max for 90 min in dehydrating environment (31°C and 51.4% humidity)	Coconut water (Doses- 50% (781 mL), 40% (625 mL) and 30% (469 mL) of the 120% of the fluid lost IPT, 30 and 60 min after exercise) *versus* CHO drink + electrolytes Control: plain water	Rehydration index, blood and urine volume and osmolarity, plasma concentrations of Na+, Cl-, K + and glucose	No difference for rehydration index, urine volume, osmolarity and [Na+] and [Cl-] Greater blood volume in the rehydration period with coconut water ↑ K + for coconut water ↑ glucose during rehydration for coconut water and CHO drink + electrolytes
(Kalman et al. 2012)	9	Crossover Randomized Placebo-Controlled Single-blind	12 M trained	Treadmill for 60 min in dehydrating environment (36°C and 48% humidity)	Coconut water (2220 mL) and concentrated coconut water (2253 mL) in the IPT and 1 h, 2 h and 3 h post-exercise *versus* Sports drink (5-6% CHO + electrolytes) Control: water	Hydration status (body mass, fluid retention, plasma osmolarity, urinary parameters) Performance (time to exhaustion). Subjective measures of thirst, stomach discomfort and fatigue	No differences for the hydration and performance measures Gastrointestinal discomfort, such as pain and swelling with coconut water
(Abbey and Rankin 2009)	9	Crossover Randomized Placebo-Controlled	10 M experienced soccer players	High intensity run (5 sets) and specific soccer tests followed by progressive run to exhaustion	Honey (8.8 mL/kg, containing 0.5 g/kg of CHO; 30 min before and during the specific test interval) *versus* CHO electrolyte sports drink diluted at 6% *versus* Lemonade-flavored drink sweetened with aspartame + sodium (isoglycidic/isovolumetric)	Performance (5 sets of high intensity run, agility tests, progressive run to exhaustion) IL6, IL10, IL-1ra, ORAC, glucose, insulin and cortisol	↓ Time of progressive run to exhaustion for all treatments No differences for other performance measures Attenuation of ↑ IL-1ra with honey No differences for IL6 and IL10, ORAC, glucose and insulin among treatments
(Hodgson, Randell, and Jeukendrup 2013)	10	Crossover Randomized Placebo-Controlled Single-blind	8 M cyclists/triathletes	Cycle ergometer at 55% of VO_2 max for 30 min and at 70% of VO_2 max for 45 min	Instant coffee (5 mg/kg of caffeine in 600 mL of water 1 h before exercise) versus	Oxidation of CHO and FA, levels of fatty acids, glucose, glycerol, lactate, and performance time	No differences for CHO and FA oxidation between coffee and caffeinated beverage ↑ glycerol, glucose,

(*continued*)

Table 3. Continued.

Author/Year	PEDro	Study design	Population	Exercise protocol	Intervention	Parameters	Outcome
					Caffeinated beverage (5 mg/kg of caffeine in 600 mL) versus Control: decaffeinated coffee (isovolumetric)		free fatty acids, lactate production and 5% performance ↑ for coffee and caffeinated beverage
(McLeay et al. 2012)	8	Crossover Randomized Placebo-Controlled	10 F practitioners of aerobic and resistance exercises	Strenuous eccentric contractions of the quadriceps (300 repetitions using an isokinetic dynamometer)	Blueberry shake (200 g blueberry + 50 g banana + 200 mL commercial apple juice, 5 h and 10 h before exercise, IPT, 12 h and 36 h after exercise) *versus* Shake 25 g dextrose + 50 g banana + 200 mL commercial apple juice (isocaloric)	Performance (torque during eccentric, concentric and isometric actions) ROS, carbonylation of proteins, FRAP antioxidant capacity, CK and IL-6	accelerates the recovery of muscle peak isometric strength, ↓ Eccentric, concentric and isometric torque for both treatments, ↓ ROS after 36 h for blueberry ↑ antioxidant capacity for blueberry No differences for the other variables
(Kalpana et al. 2013)	5	Crossover Randomized Controlled	15 M cyclists	Cycling to 70% of VO2 max to exhaustion (three sessions)	Sugarcane juice (3 mL/kg of solution) – 67 mL sugarcane juice + 33 mL water for 6% CHO or – 200 mL pure juice for 9% CHO Every 20 minutes during exercise and after exercise versus Sports drink, 6% CHO solution (25 g + 385 mL of water) and 9% CHO solution (25 g + 255 mL of water) Control: water	Glucose, lactate, plasma volume, hemoglobin, hematocrit, HR and time to exhaustion	Greater ↑ glucose for sugarcane juice No significant differences in lactate, plasma volume, HR and time to exhaustion
(Morillas-Ruiz et al. 2005)	6	Randomized Placebo-Controlled Double-blind	26 M trained cyclists	Incremental test on a cycle ergometer at 70% of VO_2 max, for 90 min	Black grape antioxidant drink (3 mL/kg black grape (81 g/L) + raspberry (93 g/L) + red currant (39 g/L) 15 min before and every 15 min during the test) *versus* Drink without antioxidants (maltodextrin – 80 g/L, whey- 2.5 g/L)	Training time and cardiorespiratory parameters TBARS, CK, protein carbonylation, urinary concentration of 8-OHdG	No differences for training time and cardiorespiratory parameters for treatments No difference in TBARS, 17% and 31% ↑CK for grape drink and control, respectively 29% ↓ in protein carbonylation for grape drink ↑ urinary excretion of 8-OHdG in the control group
(Cramer et al. 2015)	6		11 M	warm up 10-min at 55% Wmax followed			no differences in the blood glucose and

		Crossover Randomized Controlled		by a series of 10 intervals	Fast Food at 0 and 2-hr of recovery ***versus*** Sports supplements	Muscle glycogen, Blood glucose, Blood lipids, Serum insulin	insulin, rates of glycogen recovery between groups, no difference across the diets for TT performance
(Nieman et al. 2012)	6	Crossover Randomized Controlled	14 M trained cyclists	Two bicycle time trials of 75 km	Banana (0.2 g/kg containing 0.4 g/kg of CHO every 15 min) *versus* Carbohydrate drink diluted at 6%	Glucose, GR, MO, PHAG, F2-isoprostanes, FRAP, GM-CSF, IL-6, TNFα, IFNγ, IL-1b, IL-2, IL-8, IL-10 and IL-12	No differences for glucose, performance, inflammation, oxidative stress and innate immunity among treatments Greater ↑ IL-10, IL-8, FRAP and dopamine for banana

Legend: ↑: statistically significant increase; ↓: statistically significant decrease; Ca: calcium; CHO: carbohydrates; CK: creatine kinase; CRP: C-reactive protein; FA: fatty acids; F: female; FMD: flow-mediated dilatation ; FRAP: ferric reducing antioxidant power; GR: granulocytes; GSH: reduced glutathione; HDL-c: high density lipoprotein cholesterol; HR: heart rate; IFNγ: interferon gamma; IL: interleukin; IPT: immediately post-training; K: potassium; LDH: lactate dehydrogenase; LDL-c: low density lipoprotein cholesterol; Mb: myoglobin; MVC: maximal voluntary contraction; MO: monocytes; MHR: mean heart rate; M: male; Mg: magnesium; Na: sodium; ORAC: oxygen radical absorbance capacity; 8-OHdG: 8-Oxo-2′-deoxyguanosine; PTN: protein; PHAG: phagocytosis; SPE: subjective perception of exertion; TG: triglycerides; TBARS: thiobarbituric acid reactive substances; TNFα: Tumor necrosis factor alpha; TAC: total antioxidant capacity;VO_2max: maximal oxygen consumption.

An increased blood volume and plasma potassium concentration was noted for coconut water compared to a carbohydrate-electrolyte beverage (Saat et al. 2002). Improvements in parameters associated with cardiometabolic health such as vasodilation and lipid and glucose profiles was observed for tomato juice versus a carbohydrate-protein bar (Samaras et al., 2014). Finally, an increase in time to exhaustion after a protocol for depletion of glycogen with chocolate milk versus a carbohydrate drink or electrolytic beverage was observed (Pritchett et al. 2009; Thomas, Morris, and Stevenson 2009).

No significant differences were found between food and supplements in the five other studies. Comparisons were caffeine versus coffee when performance in a time trial test was evaluated (Hodgson, Randell, and Jeukendrup 2013) and sugarcane juice versus commercial sports drinks for total exercise time (Kalpana et al. 2013). Also, coconut water versus carbohydrate electrolyte was tested for hydration parameters (body mass, fluid retention, plasma osmolality, urine specific gravity) and performance on a treadmill exercise until exhaustion (Kalman et al. 2012), and showed similar results to protein and carbohydrate drink based on cocoa versus a beverage containing protein and carbohydrates added with natural cocoa, varying flavonols content for the variables CK, and perceiving soreness in muscle function (Peschek et al. 2013). Even different fasting foods were investigated and showed to have a similar effect on glycogen resynthesizing parameters when compared to different types of supplements (Cramer et al. 2015). Furthermore, commercial supplements were not superior to foods in any of the 16 studies.

Discussion

The line of research that investigates the ergogenic potential of foods either alone or in comparison to supplements is something new, judging by the dates of the publications found in this review with an average dating back to only 20 years ago. Despite being a recent line of research, the number of publications is still far from the volume of publications for sports supplements, but the 71 studies found enable an overview of the ergogenic effects of different foods. There were only six studies with cherries, three studies with dark chocolate, and three studies with bovine colostrum. There were also only two studies with each of the following foods: chocolate milk, pomegranate, grape juice, and coffee. There were also many singular publications involving one food (as can be seen in Table 2). The only exception is beetroot, which added 16 of the 71 studies selected for this review. Also noteworthy is the fact that only two of the 71 studies were from the same research group. This implies there are still no research laboratories which have food as their central line of research. Thus, it should also be noted that the number of available studies is reasonable, but the body of evidence for each food is still incipient or non-existent.

It is known that high-level athletes respond much less to the ergogenic effect of most of the resources because their training has already exploited the maximum of their genetic and physiological capacity. In fact, only six of the 71 studies were done with high level athletes (Hoon et al. 2014; Nishizawa et al. 2011; Paton, Lowe, and Irvine 2010; Peschek et al. 2013). Among these, one demonstrated an ergogenic effect (Paton, Lowe, and Irvine 2010), which is a very encouraging indication, despite the fact that this small number of studies still leaves an incipient amount of state of the art information/data on the ergogenic effect of food for high level athletes.

In any case, studies with recreational athletes have become increasingly relevant in recent decades and will become even more interesting in the years to come. This is because the popular concept of what sport is for everyone, not just for genetically gifted athletes, has grown all over the world. The demonstration of this is the number of runners, cyclists, swimmers and recreational triathletes which has increased vertiginously in street competitions in recent years (Buist et al. 2007; Salgado and Chacon Mikahil 2006).

Physical performance

Improvement in physical performance is the most important ergogenic effect. In fact, the most investigated dependent variable in selected studies was any physical performance variable as the main outcome. There were 11 studies with test to exhaustion, nine studies with oxygen consumption and anaerobic threshold, and eight with intermittent exercise, totaling 39% of the selected studies.

Of these studies, the great majority was carried out with cyclical sports. The justification for this fact is that sports of this nature have a higher degree of reproducibility in the laboratory using an ergometric treadmill or bicycle. On the other hand, some research groups have tested the ergogenic ability of food in outdoor conditions (Howatson et al. 2010; Levers et al. 2016). This could be more ecologically valid, however, the great limitation of these kinds of studies is that the climatic conditions undergo fluctuations on different days of experimental protocol, characterizing a methodological bias (depending on the study design).

The interesting fact is that the results of articles are favorable for the ergogenic effect of foods, independently of environmental conditions, which confers a more robust aspect to the evidence presented herein. This scenario places food as a promising new ergogenic resource for athletes, in addition to fulfilling the basic mission of meeting the energy demands of training. Obviously, training should always respect food action regarding the metabolic requirements of interest.

Post exercise recovery

Exercise induced muscle damage is a condition characterized by transient ultrastructural myofibrillar disruption, which causes a decrease in muscle strength and power, DOMS, swelling, reduced range of motion of the affected limb, systemic efflux of myocellular enzymes and proteins (Peake et al. 2017). Exercise-induced muscle damage (EIMD) result for athletes has a direct impact on performance, muscle soreness (Byrne, Eston, and Edwards 2001), exercise capacity (Meamarbashi and Rajabi 2015) and disturbed sense of force production and limb position (McHugh et al. 2001).

A range of physiotherapeutic (Torres et al. 2012), nutritional (Owens et al. 2019), and pharmacological (Billin et al. 2018) strategies have been evaluated to investigate their effectiveness in restoring muscle function, relieving muscle soreness, and reducing intramuscular inflammation after exercise.

It is important to highlight nutritional tools which promote attenuation of muscle damage, since this phenomenon can affect the ability to perform exercise. In this perspective, studies demonstrate a decrease in loss of strength accompanied by increased markers of muscle damage, oxidative stress and inflammation following a training session or training protocol. On the other hand, some foods have been shown to be helpful in attenuating this scenario, especially saffron (Nicol et al. 2015) and cherry (Kuehl et al. 2010).

Oxidative stress and inflammation are indicators of the impact of exercise, degree of recovery and nutritional adequacy (Cipryan 2017). The reason that reduced levels of these variables are considered ergogenic is because the most accepted theories of overtraining put oxidative stress and systemic inflammation prominently into the etiology of this phenomenon (Margonis et al. 2007; Smith 2000). Therefore, foods that have the ability to increase antioxidant capacity, reduce oxidative stress and systemic inflammation become important allies in athlete training programs.

Consumption of antioxidant/anti-inflammatory foods or supplements has been questioned because the desired effect of an exercise session is precisely to promote redox imbalance so that the body will restore its endogenous antioxidant system (Gomes, Silva, and Oliveira 2012). The argument of these researchers is that the most effective strategy to increase the endogenous antioxidant/anti-inflammatory capacity may be inducing a state of oxidative stress and inflammation prompted by exercise, which in turn would stimulate the cellular antioxidant/anti-inflammatory defense mechanisms as adaptive processes of the exercise.

Given this premise, (Paulsen et al. 2014) demonstrated that supplementation with vitamins C (1000 mg/day) and E (235 mg/day) for ten weeks affected the acute cellular response, hampering the increase of strength and altering protein signaling in individuals undergoing strength training, in addition to resulting in negative long-term effects on the adaptation to resistance training. However, Cumming et al. (2014) did not confirm this negative effect; they showed that supplementation with vitamins C and E for 11 weeks did not affect the adaptations to training in the long-term in the endogenous antioxidant systems of individuals undergoing endurance training.

This controversy can be reasonably explained by classifying the studies included in this review according to the acute and chronic responses to food intake that were observed in the selected experiments. In the majority of the studies in which the experimental protocols were performed with only one or two exercise sessions, the acute response involved reductions in inflammatory or oxidant activities; these results do not support the argument claiming deleterious effects of products with antioxidant properties on the endogenous antioxidant response. However, if it is true that antioxidant intake inhibits endogenous antioxidant activity, then it is at least expected that the antioxidant activity in the experimental groups in the studies where some food was chronically ingested (i.e. for several weeks) would be decreased relative to the control groups.

Food versus supplement

In some cases, when the effect of the food was tested against a supplement, it was impertinent; for example, Lunn et al. (2012) compared the effects of milk intake on a carbohydrate beverage in assessing hypertrophy parameters in runners. It would be interesting to compare this same food with whey protein, which has a more similar nutritional profile to the composition of the tested food, and if the exercise modality had been one which better explores muscular hypertrophy.

Final considerations

In summary, this review has shown that food research as an ergogenic resource has been a reality since the current decade, that there are currently a reasonable number of studies on the subject, and a number of publications in the growing phase. However, the studies are from several laboratories without any of them having several publications on the subject, indicating a lack of research lines dedicated to this subject. In addition, few foods have enough publications to support a body of evidence. This indicates the need to grow this line of research. There are several foods which have been studied, but there is a lack of evidence on each of these foods, and in some cases there is only one publication; thus, another gap that needs to be remedied is the impossibility of determining the ideal dose and administration time for each effect of the food.

Considering the limitations of the scientific production volume, the available data presents food as a very interesting ergogenic agent to improve performance, accelerate recovery and improve physiological behaviors that directly affect the performance of athletes and the capacity to maintain high training loads in this population.

Author contributions

M.S.C, L.T.T and L.T.T wrote the article and did the search for articles. V.R.L, R.A.T and J.A.S were responsible for developing the protocol. ASS was responsible for all procedures performed on the manuscripts. All authors read and approved the final manuscript.

Disclosure statement

There are no conflicts to declare

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