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Sustainable Diets for Athletes

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Abstract

Purpose of Review Sustainable production and healthy consumption have been the topic of recent publications. Due to the high environmental impact of the current food system, significant changes in how food is produced, distributed, and consumed are needed in all sectors and groups. While most research in sustainable diets has focused on the general population, limited work has involved athletes. The purpose of this review is to summarize the current knowledge on food and sustainability in athletes.

Recent Findings Meeting but not exceeding protein requirements through flexitarian and plant-based approaches, reducing packaged foods and food waste, and prioritizing seasonal produce were identified as possible mitigation options in athletes.

Summary There is urgency for more research on plant-centric, whole food–based strategies for post-exercise skeletal muscle and training adaptation, the effect of sustainable diets on health and performance, and behaviors to reduce packaging and food waste in athletes.

Keywords Food systems · Plant-based · Flexitarian · Protein · Sports nutrition · Environment · Food literacy

Introduction

Human-induced global warming through greenhouse gas emissions (GhGe) has reached approximately 1 °C above pre-industrial levels in 2017. In 2018, the Intergovernmental Panel on Climate Change (IPCC) released a call to action to reduce current trends to stay below 1.5 °C of warming [1•].

Sustainability was first defined in 1987 by the Brundtland Commission as follows: "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. Recently, the United Nations published 17 sustainable development goals (https://sustainabledevelopment.un.org/sdgs). The purpose of these goals is equally to find synergies among them and promote win-win-win solutions for planetary health, human well-being, equity, and prosperity [3].

As part of sustainable developments, a sustainable diet is a decade-old concept that was first defined by participants of the 2010 International Conference organized by the Food and Agriculture Organization and Biodiversity International. A sustainable diet is "a diet with low environmental impacts which contributes to food and nutrition security and to healthy life for present and future generations" [4]. It has also been recognized that sustainable development can only occur if food system problems are addressed trans-disciplinarily, promoting systems thinking, linking ecological with human health and wellbeing, while ensuring social equity and economic prosperity [5•]. Thus, "a sustainable food system is protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy, while optimizing natural and human resources" [4].

Globally, few countries have integrated sustainability concepts into governmental dietary guidelines [6]. Nevertheless, many non-governmental organizations [1•, 3, 7•], along with an impressive body of scientific literature [5•, 7•, 8–11, 12•,

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13], have released calls to action for changes in agricultural production and eating practices to conserve natural resources and promote healthy ecosystem services including a thriving food system that is accessible, healthy, and prosperous for communities.

Recently, the EAT-Lancet Commission called for the "Great Food Transformation," for the developed world, to promote healthy diets from sustainable food systems. Such dietary shifts would address climate change, diet-related illness, and food insecurity by creating solutions for the benefit of people and the planet jointly. The authors suggest more plant-based dietary approaches rich in vegetables, fruits, legumes, whole grains, nuts, and seeds. Substantial shifts away from foods that are harmful to those that are beneficial for human and planetary health would likely reduce diet-related mortality, lower health care costs, and protect planetary resources [7•].

Athletes and active individuals have only recently been included in the discussion of sustainable diets [14, 15, 16••, 17•, 18••, 19•]. For the most part, these publications have diffused the knowledge from sustainable food systems to the diets of athletes with the intent to reduce environmental impacts, while maintaining health and performance in exercising humans.

Athletes have greater energy and nutrient needs than the general population [20–22]. While it is important that athletes meet dietary guidelines to maintain health and improve performance capacity, studies consistently show that athletes exceed protein intakes [23–25], are prone to follow food trends [26, 27], and use a large number of dietary supplements, especially protein powder, often with no clinical reason [28–30]. Thus, some athlete groups might fall into what Garnett [31] called the category of the "healthy and wealthy," consuming foods consistent with dietary trends to gain a performance edge with no or limited knowledge of and no consideration of planetary impacts.

Thus, the purpose of this review is to summarize the current knowledge on food and sustainability with special attention to athletes' diets. Though sustainability encompasses multiple dimensions, this review will focus on the environmental issues with the objective of presenting recommendations toward more environmentally friendly food choices, while maintaining the performance edge of tailored sports nutrition guidance.

The Environmental Impact of Food and Diets

With the development of life cycle assessment (LCA) of agriculture and food and the increasing availability of data for many food products, countries of origin, and production methods, the analysis of complete diets has become more common [32, 33]. LCA is particularly suitable for the analysis of food production and consumption, since it considers a life cycle of a product, and therefore can represent a food supply chain, including manufacturing of the agricultural means of production, farming (including direct emissions), transport, processing and storage of food, and finally, food consumption [34]. In contrast to footprint methods, which consider a single aspect like GhGe, land use, or water use, LCA performs a comprehensive environmental assessment by including all relevant environmental impacts. These include climate change, eutrophication, acidification, photochemical ozone formation, stratospheric ozone depletion, ecotoxicity, abiotic resource use, water scarcity, biodiversity, soil quality, and impacts of particulate matter and toxic substances on human health. Thus, LCA is a method of system analysis, defining clear system boundaries, so that strength and weaknesses of different systems or alternatives can be compared [35]. A typical life cycle of a food product is shown in Fig. 1.

The contribution of life cycle stages to the total environmental impact varies according to the food group [12•] (Fig. 2). The impacts are generally dominated by agricultural production (crop production, livestock production, and land use), which is more important than processing, packaging, and transport. The contribution of land use change is particularly high, whenever deforested areas or former peatland (i.e., rich organic soil) is used (e.g., in the case for soybeans and palm oil). Transport is mainly relevant for fruits and vegetables, where 1 kg of product causes relatively low impacts and, therefore, transport gains relative importance (Fig. 2). Furthermore, air freight strongly increases the environmental impact [36]. Packaging can be important for some food products including liquids [37] and could potentially be more important for athletes, who are often eating on the go. However, if protective packaging is reduced leading to more food waste, the total impact is likely to increase [38]. Figure 2 shows life cycle data of various food groups.

Systematic reviews on the environmental impacts of different diets [39, 40, 41•, 42] show that reducing or avoiding animal-sourced food (ASF), particularly meat, decreases the environmental impacts of the food system. Consequently, vegan diets, followed by vegetarian diets, show lower environmental impacts than omnivorous diets [41•, 43–46]. The effects are higher on climate change (− 40 to 50% for vegan and − 30% for vegetarian) and land use (− 50 to 60% for vegan or vegetarian) than on water use (− 30% for vegetarian) [40]. Vegetarian diets contain more fruits and vegetables, which often stem from irrigated fields. The higher environmental impacts of ASF are mainly caused by the losses during the conversion of feed (e.g., corn, soy, hay) to animal products. Further, additional emissions from animal husbandry, such as methane from enteric fermentation and nitrogen and phosphorus emissions from manure management [12•], contribute significantly to a higher environmental impact of meat. However, it is not necessary to have completely vegetarian or vegan diets to reduce environmental impacts, since it is also

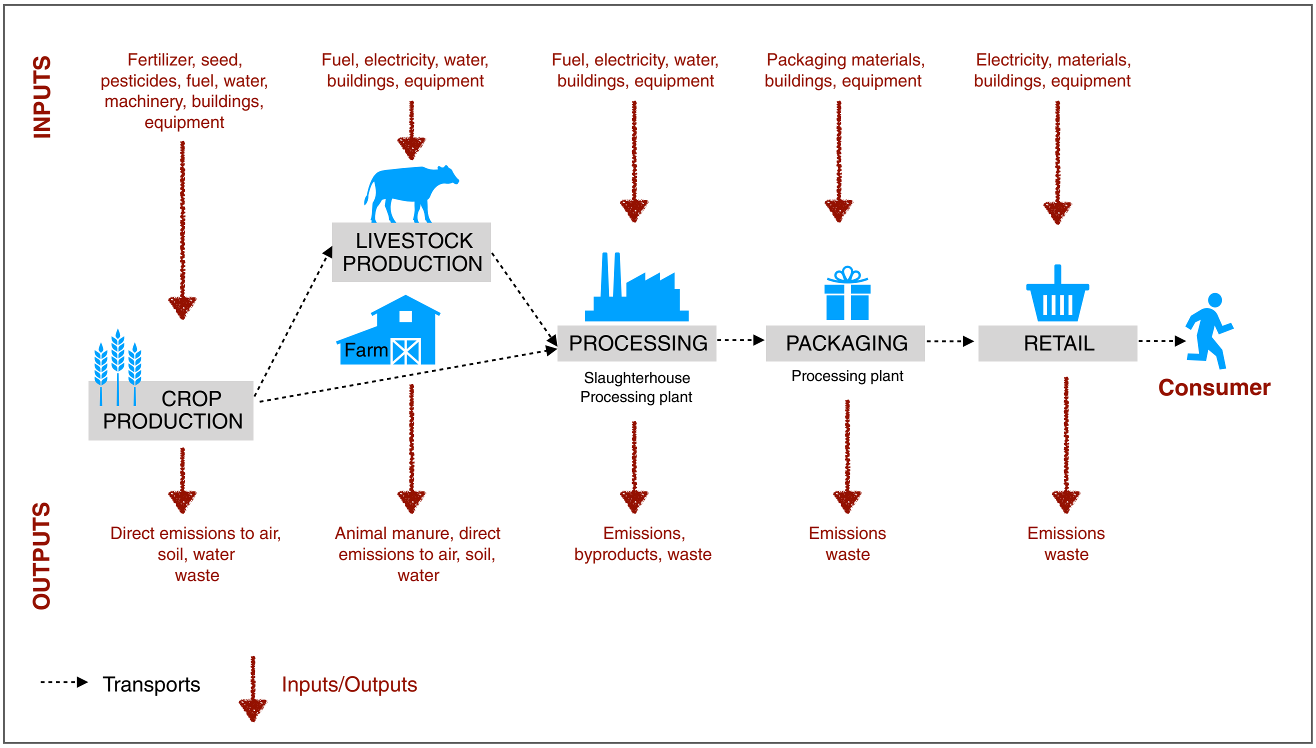

Fig. 1 Typical life cycle of a food product

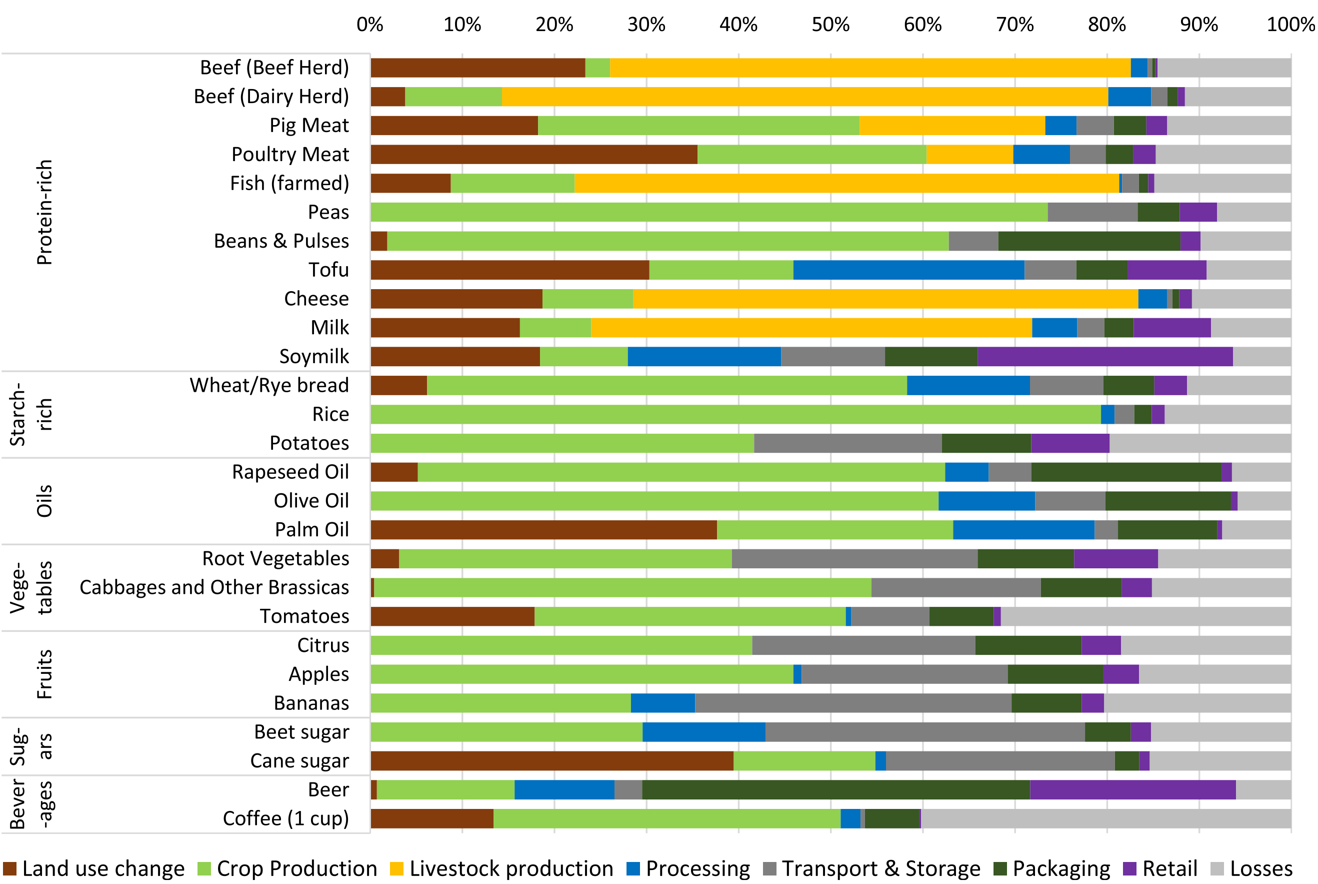

Fig. 2 Contribution of different life cycle stages to the greenhouse gas emissions of selected food groups (based on data from Poore and Nemecek [12•])

possible to define flexitarian diets with less ASF and considerably lower environmental impacts [41•]. This approach could be meaningful in athletes, as it allows for meeting but not exceeding protein requirements.

Following healthy dietary guidelines, as recommended nationally, is generally favorable for the environment [47], but this is not always the case [46], depending on what is used to replace meat [40, 42]. Thus, the impact on the environment depends on the context, with larger effects in high-income countries [48]. Cultural preferences [49] and individual behavior [50, 51] also play an important role for the environmental footprints of food consumption.

When comparing different food products, in particular plant-based and ASF, differences in nutrient composition and nutrient quality of the products matter. Meat has significantly higher environmental impacts than plant-based alternatives [52]. However, if nutritional quality (e.g., amino acid profile of protein, protein digestibility, and micronutrients) in meat is taken into account, the differences are smaller but remain significant [53•, 54, 55, 56••]. It will be critical for the diets of athletes to ensure protein quantity, quality, and distribution relative to exercise when evaluating the environmental impact.

Several studies link the impact of food on the environment to impacts on human health [7•, 43]. Although strong synergies exist between environmental and human health impacts of diets, their association is not always clear [50]. In addition, while healthier diets are characteristic of greater diet quality due to higher fruit and vegetable consumption, these diets are also associated with greater waste of fresh produce, especially on the consumer level [57]. Beretta and Hellweg [58] highlighted the importance of food waste. Avoiding food waste, as shown in a Swiss case study, could reduce environmental impact from food by 30–40%. For athletes, food waste could be significant due to the lack of time and skills in food handling and storage and frequent travel.

Seasonality also plays a dominant role; vegetables or fruits from heated greenhouses cause significantly higher environmental impacts [59]. Therefore, the consumption of seasonal, fresh food is generally more favorable. Considering that athletes often eat in dining halls of institutions or training centers, planning menus for athletes should favor fresh seasonal fruits and vegetables, as packaged, processed, frozen, or canned foods not only elevate the environmental impacts [37, 60–63] but also may compromise flavor and nutrition [64–66]. In a recent study performed at an elite training center, higher environmental impacts were identified from frozen and canned vegetables compared to fresh options (Reguant-Closa et al., under review). While food service and support staff or athletes may not always know when produce is in season or the nutritional, flavor, and environmental ramifications of out-of-season products [64, 66, 67], food literacy approaches can remedy such gaps.

The environmental impacts largely differ also within a food product depending on its origin and the production system [12•], which shows the large mitigation potential in food production. ASFs have higher environmental impacts than plant-based alternatives, but large differences between different ASFs exist. For example, beef from beef herds needs 23× more land and causes 9× more GhGe per 100 g of protein compared to poultry meat [12•]. However, ruminants (and other roughage feeders like horses) can also use feed from grasslands, while monogastric animals (poultry and pigs) directly compete with human nutrition [68]. Often cattle are fed with concentrated feedstuffs, like cereals, corn or soybean meal, or alfalfa. In these cases, a direct competition between livestock production and human nutrition exists [69]. Compared to beef, dairy production uses the resources more efficiently and should therefore be the first choice when using grassland. Therefore, the environmental impacts are lower per unit of protein for milk than for beef [70]. The environmental hotspots of wild-caught fish are the fuel use for the trawlers and the over-exploitation of fish stocks. The latter aspect is not well covered by current LCA. For aquaculture, the production of the fish feed, water pollution, and methane emissions from fish ponds and energy use are the main drivers for environmental impacts [71].

From the literature, we can conclude that diets with less ASF and, in particular, less meat have lower environmental impacts. However, there are large differences among ASFs, since foods such as milk, eggs, and poultry have lower environmental impacts than meat from ruminants. The environmental impact of pork is in between ruminants and poultry. Part of the ruminant feed stems from grassland and is therefore not in direct competition with human nutrition. Diets following governmental nutrition recommendations tend to have lower impacts than current Western diets. A large mitigation potential lies, therefore, in changed human diets, including a reduction in meat and waste and in optimized food production.

Health and Performance Opportunities of Sustainable Diets

Defining a sustainable diet encompasses environmental, agricultural, sociocultural, health, and socioeconomic factors [6]. Athletes have specific nutritional requirements depending on training intensity and volume, performance goals, and health status [22], but considerations of environmental impacts and sustainability remain mostly elusive when tailoring diets for athletes [16••, 18••]. With the growing concerns of climate change and the evidence that consumer choice can effectively reduce environmental impacts [7•, 10, 12•, 47], the integration of sustainability in athletes' diets can no longer be avoided.

While a sustainable athlete's diet can be approached from different angles, the following section focuses on the hotspot of ASF and protein, highlighting the most environmentally impactful solutions, while also acknowledging additional important steps toward environmentally friendly eating.

Meeting But Not Exceeding Protein Requirements

The protein content of an athlete's diet is important to ensure adequate muscle protein synthesis, tissue repair, and training adaptation. Protein requirements for male and female athletes range from 1.2 to 2 g*kg body mass (BM)$^{-1}$*day^{-1} [21, 22, 72]. To support weight loss, aging, or periodized training strategies with low carbohydrate availability in athletes, higher recommendations of 2 to 2.4 g*kg BM^{-1}*day^{-1} have been described to preserve lean mass [73–79]. Unfortunately, there is lingering belief and practice to favor higher protein intakes for active and athletic individuals, with some studies showing excessive intakes as high as 4.3 g kg BM^{-1} day^{-1} [23–25].

Muscle adaptation to training is dependent not only on the amount of protein but also on the timing of ingestion. The distribution of protein through the day of about 0.25–0.31 g kg BM^{-1} meal^{-1} or 20–25 g of protein per meal through 4–5 meals positively improves muscle protein synthesis [80–82, 83•], with older adults benefiting from as much as 0.4 g kg BM^{-1} meal^{-1} [80]. It has also been recommended that 20–25 g of whey protein post exercise [83•, 84, 85] and additional protein before bedtime [86, 87] promote muscle protein synthesis [21, 82], although smaller amounts of intact protein from whole foods may be sufficient [19•, 88••]. Taken together, besides meeting overall protein requirements in athletes, adequately distributing daily portions of protein at meal times, relative to exercise and before bedtime is recommended.

Muscle protein synthesis is also determined by the quality of ingested protein. Protein quality is commonly expressed by the true ileal digestibility of essential (indispensable) amino acid score or Digestible Indispensable Amino Acid Score (DIAAS) [89]. Protein from ASF has a higher DIAAS than that of plant-based origins [89]. In exercise and to meet goals of muscle protein synthesis, the branched chain amino acids, and especially leucine [90, 91], have been identified as critical [21, 75, 80, 92–94], although this appears to be true only for isolated protein sources [95••]. While ASFs are typically more complete in indispensable amino acids with a higher DIAAS value, plant-based options do exist with slightly lower, equal, or slightly higher leucine content compared to ASF [96••]. Nevertheless, due to the less favorable amino acid composition and concomitant lower DIAAS [97] of plant-based options overall, greater quantities [54, 98] or combinations or blends [96••] are likely needed if used as protein isolates as opposed to whole foods [88••, 95••].

In addition to protein's role in muscle, there are further nutritional benefits from the ingestion of ASF, such as iron, zinc, calcium, and vitamin B_{12}, all of which are also important for athletes [22]. According to Moore [83•], even if recommended intakes post exercise increase slightly (from 0.25 to 0.31 g kg BM^{-1}), overall protein recommendations for athletes rarely exceed 2 g kg BM^{-1} day^{-1}, except perhaps for weight loss transiently [77]. Thus, evaluating carefully athletes' overall quantity, quality, and distribution of protein and avoiding excess intake is the first step to an environmentally friendly approach.

High protein intakes from ASFs, and especially red meat, are common in Westernized diets with high socioeconomic status [99] and also in some athletes [100, 101]. If high in red and processed meat, such diets are neither health-promoting [7•, 102] nor performance-enhancing [83•] nor protective for the environment [41•]. While research on whole food diets and the skeletal muscle adaptive response is still limited, preliminary data indicate that less, not more, protein is likely sufficient [75]. Thus, athletes need professional guidance so they learn to adjust protein sources, quantity, and distribution according to the evolving evidence in protein nutrition relative to exercise.

Athletes are also heavy users of dietary supplements, especially protein powders [103, 104]. Protein supplements (such as protein shakes or protein bars) are typically used by athletes to optimize muscular adaptations post exercise [29, 105–108]. While convenient [109], athletes exceed quickly recommended amounts of proteins when using these products. Besides concerns of supplement contamination [110], recent research on the microbiome also raises concerns of such practices. Especially in the absence of adequate fiber, excess protein can result in fermentation in the gastrointestinal tract, which has been associated with inflammation, damage, and dysfunction [111••]. A recent study also evaluated a 10-week supplementation trial using protein powders and their effect on the microbiota. The authors found a decrease in health-related bacteria, suggesting negative impacts from prolonged intakes of protein powders on the gut microbiota [112]. A healthy gut is associated with exercise [113] and athletic performance [114••]. Long-term protein supplementation raises concerns not only for the deterioration of individual health but also for planetary health if it leads to overall excess protein intake. Protein concentrates, such as whey, are typically by-products with high nutritional value yet relatively low environmental impact [56••]. Thus, using whey in small quantities in the post-exercise period can still meet training goals [84, 85]. However, a safe, whole food first approach, high in fiber and nutrients, without an excess of ASF and/or supplements, should be preferred in athletes to ensure optimal health, skeletal muscle support and performance, and environmental protection.

Finally, high protein intake increases satiety and can displace adequate carbohydrate intake [73]. Many athletes have suboptimal intakes of carbohydrates [115, 116], which can be detrimental to training adaptation, health, and performance [75, 117, 118]. Popular eating approaches, such as gluten-free, Paleolithic, and ketogenic diets [27, 119] or training with low carbohydrate availability [73], are also used by athletes. Such diets can be high in protein, and specifically ASF, and high in fat [31]. While these diets may provide a temporary training or a necessary clinical solution, they may also be a nutritional fad. Unfortunately, these approaches are costly in the long term, for the environment and, most likely, also for health [31, 120, 121].

Plant-Forward, Flexitarian Approaches

As ASFs have a higher burden on the environment than plant-based protein sources [12•], replacing some of the animal protein content of the diet with plants might provide sports performance opportunities. A plant-forward diet, also understood as a flexitarian approach with less meat, is generally associated with better health outcomes [43, 102] and lower environmental burden [41•].

Increasing plant-based foods from fruits, vegetables, legumes, and whole grains promotes weight and fat loss [122] due to the lower fat and energy density and higher dietary fiber content [123]. Such modifications are also mostly environmentally friendly. Increasing plant-based foods also boosts vasodilatory, antioxidant, and anti-inflammatory properties of the diet, which can lead to improved blood flow, reduced oxidative stress and inflammation, and thus, enhanced endurance performance, reduced muscle damage, and speedier recovery [124–126].

Because research on plant protein is still scarce in sports [18••], it is generally accepted that animal-derived protein is optimal for recovery, especially post exercise [127, 128]. Studies have mostly focused on isolated, high-quality milk proteins, especially whey and casein but also soy to promote muscle protein synthesis post exercise, with whey protein generally showing greatest results [84, 129–131]. Recently, co-ingestion of carbohydrate with 20 g of protein from milk, whey, or casein showed no differences in myofibrillar and mitochondrial protein synthetic rates in young men post concurrent resistance and endurance-type exercise. Protein and carbohydrate co-ingestion, however, increased myofibrillar protein synthesis compared to carbohydrate alone, which shows that protein and carbohydrate combinations post exercise are an effective nutrition strategy [131]. While plant-based proteins are not well researched, a 3-month resistance training study using whey versus pea protein supplementation compared to placebo showed no difference in muscle gain and strength between the two different proteins [132].

Further, using whole nutrient-dense foods, compared with processed or isolated equivalents, while still understudied in plants and whole meals, has shown greater impacts [133, 134] on post-exercise muscle protein balance, at lower quantity [83•], and independent of leucine content [95••]. In addition, there seems to be individual adaptation to lower protein intakes in some cultures [135] at no compromise to performance, indicated by the recent Kenyan success story in the marathon [136]. Considering climate change and the projected reductions in crop yields [137] and nutrient density, including protein [138], sustainable solutions to protein will be needed, also in athletes. Several countries have already made shifts to low-meat options within traditional food culture contexts [8, 11, 13]. Whether quality-corrected isolated or whole foods rich in protein with the lowest environmental impact [56••], mixed animal and plant blends or complementary plant combinations [139], or other low-impact options (e.g., insects [140]), sports nutrition of the future will require, at the very least, a flexitarian approach.

Flexitarian, plant-forward, or semi-vegetarian diets have become popular alternatives to fully plant-based lifestyles. Data show that flexitarian approaches, with occasional animal protein from meat, dairy, or fish, can still reduce the environmental impact of the diet [40, 141•]. These diets are also becoming more popular among athletes [27] for health, ethical, environmental, or religious/spiritual and aesthetic reasons. The EAT-Lancet Commission proposed a reference diet for human and environmental health with a recommended intake of meat of no more than 300 g (10.5 oz), and less than 100 g (3.5 oz) of red meat, per week [7•]. This is in agreement with Aiking [10], suggesting to reduce overall daily protein intake by 1/3, replace 1/3 by plant-based options, and choose 1/3 from high-quality sources [10]. On the athlete's plate, this suggests a protein flip [142], moving plant-based foods to the center of the plate, while using ASF as a topping [16••].

Plant-Based and Vegetarian Approaches

While vegetarian diets for athletes have been discussed in the past [143, 144], the popularity of such diets among athletes has re-surfaced [18••, 27]. While these approaches have been highlighted positively in the popular press [145], there are still concerns of nutrient deficiencies, suboptimal training adaptation, and performance impacts [27, 146–149]. Due to reduced protein quality of plant-based proteins [89], protein recommendations for vegans/vegetarians are likely greater [150] than for omnivores. Employing the DIAAS in athletes, Ciuris et al. [151] showed significantly lower scores using prospective food records in a cross-sectional sample on omnivorous and vegan/vegetarian endurance athletes with isocaloric diets. These lower scores also related linearly to differences in lean body mass and strength measures. While this study did not examine endurance performance variables, it seems prudent that athletes on plant-based diets focus on adequate protein quantity and quality, choosing from diverse food sources over the day to ensure complementarity action of amino acids such as lysine and methionine [149]. Though still scarcely studied, most research on performance in vegan/vegetarian athletes neither shows performance gains or losses [18••].

Few studies have investigated the impact of a plant-based diet on athletic performance. The majority of these studies show no difference in endurance capacity [147, 148], endurance performance [148, 152], or performance in strength/power tasks [152]. These studies were summarized by Craddock et al. [148] and Lynch et al. [18••], indicating no performance differences among omnivores, vegetarians, and vegans. Most of the studies have been centered on aerobic capacity and performance. Lynch et al. [152] evaluated the cardiorespiratory capacity, showing significantly higher VO_2 max values in female vegetarian athletes versus omnivorous athletes. But, no significant differences were found in the male athletes [152]. More recently, Nebl et al. [147] analyzed the maximal exercise capacity of recreational runners following an omnivorous, lactovegetarian, and vegan diet with no differences in exercise capacity, adding to the literature that plant-based diets have no negative impact on performance. Fewer studies have focused on the effect of a vegetarian or vegan diet on strength and power. Lynch et al. [152] examined the strength (by peak torque for leg extension) cross-sectionally of vegetarian versus omnivorous athletes with no differences. Some vegetarian athletes may have less lean body mass than omnivorous athletes [151], which could impact performance especially in strength and power sports, but thus far, no studies have shown this and there are many athletes on plant-based diets that seem to succeed in their sports [145, 153].

Plant-based diets may also have health benefits that could boost performance in the long term. It is well documented that plant-based diets reduce the risk of chronic illness such as cardiovascular disease, diabetes, metabolic syndrome, and cancer [154–157] and all-cause mortality [158]. Plant-based diets are associated with lower body mass index [159] and metabolic and inflammatory indices consistent with better health outcomes [160–162]. Recently, a plant-based diet was suggested for endurance athletes because of its cardioprotective effect and possible performance advantage, the latter may be due to the high carbohydrate intake of these diets, among other reasons [163••].

On the opposite spectrum, there has been concern that vegetarian diets could increase the risk of eating disorders. Because plant-based diets are naturally lower in fat and calories [163••], they might help athletes with energy restriction. Thus, it is unclear that plant-based diets per se cause eating disorders [164, 165]. In fact, studies have repeatedly shown no significant differences in the health [166, 167] and immune status [168], or micronutrient intakes [146], between vegetarian and omnivorous athletes. In addition, a diet rich in vegetables, fruits, legumes, and diverse grains is also rich in antioxidants and could provide a broad range of nutrients available in limited amounts in Westernized diets [146, 163••]. Nevertheless, athletes on plant-based diets should be vigilant regarding energy, protein, iron, zinc, vitamin B_{12}, and omega 3 fatty acids, as these nutrients could be reduced, increasing the risk of suboptimal intakes [18••, 169]. Finally, plant-based diets are known to be high in grains, legumes, and beans which can increase antinutritional factors such as phytates [170, 171]. These factors, however, can be reduced through various methods of soaking, sprouting, fermenting (sourdough), and nixtamalizing (for corn-based foods). These processes, some of which are traditional, can increase the bioavailability of nutrients, including amino acids [172].

In conclusion, sustainable sports nutrition strategies must first ensure athletes meet but not exceed protein recommendations. Choosing a variety of protein sources from animals and plants, distributed according to meal patterns, exercise, and sleep will be sufficient to achieve optimal muscle repair, protein synthesis, and training adaptation. The flexitarian approach could be a win-win-win strategy for athletes, since overall protein needs are likely met, protein quality is met, and sustainability guidelines are met. Finally, athletes may also choose to integrate plant-based meals, days, or diets as long as these meet health and performance goals and prevent suboptimal energy and nutrient intakes. Due to athletes' lifestyles, other environmental hotspots, besides ASF, likely include processed, packaged, and wasted foods (Table 1). There is a great need for research in these areas to develop sustainable practices for athletes.

Sustainable Diets for Athletes: The Role Of Sports Dietitians, Teams, And Institutions

Sustainable dietary practices include a broad range of areas. The sports dietitian is the professional to ensure awareness, knowledge, and skills in sustainability practices are promoted in athletes, coaches, the support team, and institutions (e.g., national sporting organizations or universities). There are several concept papers published that can act to support the integration of sustainability into curricula [173•, 174] and nutrition practices of registered dietitians and fitness professionals [15, 16••, 175•].

The Sports Dietitian

Athletes are mainly concerned about performance enhancement through nutrition. However, young people are becoming more aware of the impact the current food system exerts on people and the planet. There are many eye-opening

Table 1 Five steps to sustainable diets in athletes

Area to reduce	Area to rethink and redo
1. Reduce animal-sourced foods (especially red and processed meat)	Increase plant-based foods; consider flexitarian, plant-forward approaches
2. Limit protein supplements	Practice food-first approaches using whole foods whenever possible
3. Reduce processed, frozen, and canned foods	Increase food literacy and prioritize locally grown, seasonal, fresh food
4. Reduce food waste	Teach purchasing, cooking, storage, food safety, and food literacy
5. Avoid unnecessary packaging	Use sustainable options but evaluate solutions in the light of food safety and food waste

experiences for athletes to ignite awareness of their own actions (e.g., conducting a food waste study at home, evaluating reusable packaging, exploring local food sources). To integrate sustainability in sports nutrition practice, sports dietitians will need to provide context, choose the right timing, and create learning opportunities through food literacy. Food literacy is defined variably [176, 177] but focuses on knowledge and skills related to food and nutrition, connecting learners to where food comes from, how and when it is grown, and by whom. Food literacy also includes know-how in purchasing and kitchen work to learn what is in season and available fresh and how to assemble, cook, eat, and fuel as well as safely preserve, store, and prepare food for eating on the go. Providing a visit to a farmer's market and guidance about direct-to-consumer purchasing options when training at home is a great introduction. Food citizenship [174, 178] develops gradually, as young people begin to understand that their food choices either support or threaten a healthy, environmentally protected, and just food system. When athletes travel or are in competition, these place-based approaches will flexibly adjust, although travel also gives rise to cultural exposures depending on the destinations, time availability, and food access logistics. It is the sports dietitian's role to teach sustainable travel practices with packaged foods and vessels (e.g., water bottles) that are permitted at airport and are safe and environmentally friendly.

The sports dietitian is responsible for the athlete's understanding and implementation of relative quantity, quality, and distribution of proteins according to performance goals. Sports dietitians should understand the reasons for and differences in plant-based and plant-forward strategies and help athletes integrate these into their daily and weekly training diets using personalized nutrition and creative cooking techniques using the protein flip [16•, 142]. A recent validation study on the athlete's plate educational tool, conducted with sports dietitians at a national training center, found a higher protein content than recommended (up to 2.9 g kg BM^{-1} day^{-1}), with 70% of total daily protein intake coming from ASF when sports dietitians were asked to make plates according to training load and two weight categories for males and females [17•]. In a follow-up study, LCA showed higher environmental impacts for ASFs compared with other foods on the plate, plates made for hard training days, and those made for male athletes (Reguant-Closa et al., under review). While the athlete's plate model will be revised to integrate sustainable practices, it is also important to adjust protein recommendations as discussed in this article.

The Team

Sustainability practices should be woven through the team's philosophy, which could address travel, waste, and recycling policies. Further, food visions, as part of the team's sustainability plan, ensure environmentally friendly eating practices are not only promoted but also communicated to the local community. A team's food vision could include reduction of excess red meat; incorporation of plant-based meals and days; reduction of food and packaging waste; increase in locally purchased and seasonal products for recovery centers, training tables, and catered meals; and prioritizing food establishments that offer locally sourced and sustainable options. To our knowledge, sports teams have yet to put forward their food visions.

Institutions and Organizations

Sporting organizations, universities, and national training centers can make the biggest impact through changing food procurement processes. The International Olympic Committee (IOC) has developed the Sustainability and Legacy Commission, which aims at increasing awareness and inclusion of sustainability considering the Olympic Movement. Following this goal during 1999, the IOC developed the Olympic Movement's Agenda 21: Sport for sustainable development with the objective to encourage members of the movement to play an active part in the sustainable development of the planet [179]. This document included sections for health and access to healthy food but did not specify concepts related to sustainable diets. During the London 2012 and Rio 2016 Olympic/Paralympic Games, sustainability initiatives pertaining to food procurement and diet design were instated for the first time [180, 181]. During the 2012 London Olympic Games, food provision and nutrition of the Olympic menu was assessed among sports dietitians at the Games. While sustainability was integrated in the Olympic menu, very few were aware of this [14]. A follow-up paper about the food provision at the Rio 2016 Olympic/Paralympic Games unfortunately did not include food sustainability in the assessment [182]. This highlights the urgency for greater integration in menu assessment and procurement policies/food visions that include sustainable practices.

While institutional procurement regulations vary by contracts, food service managers can emphasize plant-based and plant-forward options [142], reduced ASF serving sizes, sustainable protein options, locally sourced seasonal vegetables and fruit, a minimum of packaged liquids and snacks, and a reduction in food waste.

Institutions and organizations hosting sporting events should also consider initiatives such as the Green Sports Alliance [183] and the Sports for Climate Action [184]. The wastefulness of sporting events has recently been addressed at the London Marathon and Tokyo Olympics, and various sports have integrated sustainable practices as part of their principles (e.g., ski mountaineering) [185–187].

Conclusion

Very few sports nutrition recommendations and guidelines include sustainability and even less integrate the environmental impact of food choices in a quantifiable manner. There is a significant research gap on plant-centric, whole food–based strategies for post-exercise skeletal muscle and training adaptation. More research is needed on the effect of sustainable diets on athletes' health and performance. Finally, research to reduce packaging and food waste in athletes is also needed. Moreover, dietary guidelines and effective educational tools, specifically for active and athletic individuals, need to align with sustainability principles to promote win-win-win solutions for healthy eating, athletic performance, and a sustainable future.

Compliance with Ethical Standards

Conflict of Interest Nanna L. Meyer, Alba Reguant-Closa, and Thomas Nemecek declare no conflict of interest.

Human and Animal Rights and Informed Consent All cited studies by the authors were approved by institutional review boards of their respective institutions.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1.• IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.
2. Brundtland G. Report of the World Commision on Environement and Development: our common future, vol. 400: Oxford Pap; 1987. https://doi.org/10.2307/2621529.
3. United Nations Assembly Transforming our world: the 2030 Agenda for Sustainable Development. New York United Nations. 2015;(1):1–41. DOI: https://doi.org/10.1007/s13398-014-0173-7.2.
4. FAO. Sustainable diets and biodiversity. Rome: Food and Agriculture Organisation of the United Nations (FAO); 2010. p. 1–309.
5.• Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, et al. The global syndemic of obesity, undernutrition, and climate change: the Lancet Commission report. Lancet. 2019;393(10173):791–846. https://doi.org/10.1016/S0140-6736(18)32822-8 **This expert report by the Lancet Commission addresses the pandemics of obesity, undernutrition, and climate changes as a global syndemic or synergy of epidemics, proposing recommendations with concrete actions to address the problems across their systems.**
6. FAO. Plates, pyramids, planets. Developments in national healthy and sustainable dietary guidelines: a state of play assessment: Food and Agriculture Organisation of the United Nations (FAO) and the Food Climate Research Network at The University of Oxford (FCRN); 2016. p. 1–80.
7.• Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. Lancet. 2019;393(10170):447–92 http://www.ncbi.nlm.nih.gov/pubmed/30660336. **This scientific publication from the EAT-Lancet Commission is a call to action for the great food transformation to accommodate the need to feed a growing global population with healthy food from sustainable foods systems. The Commission proposes a universal healthy reference diet with a decrease in consumption of red meat, sugar, and refined grains and an increase in vegetables, fruits, whole grains, legumes, and nuts for the benefit of health and sustaining a healthy planet.**
8. Saxe H. The new Nordic diet is an effective tool in environmental protection: it reduces the associated socioeconomic cost of diets. Am J Clin Nutr. 2014;99(5):1117–25. https://doi.org/10.3945/ajcn.113.066746.
9. Dooren C Van, Aiking H. Defining a nutritionally healthy, environmentally friendly, and culturally acceptable Low Lands Diet.

In: Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014). San Francisco: ACLCA, Vashon, WA, USA; 2014.
10. Aiking H. Protein production: planet, profit, plus people? Am J Clin Nutr. 2014;100(S.1):483–9. https://doi.org/10.3945/ajcn.113.071209.
11. Esteve-Llorens X, Darriba C, Moreira MT, Feijoo G, González-García S. Towards an environmentally sustainable and healthy Atlantic dietary pattern: life cycle carbon footprint and nutritional quality. Sci Total Environ. 2019;646:704–15. https://doi.org/10.1016/j.scitotenv.2018.07.264.
12.• Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science. 2018;360:987–92. https://doi.org/10.1126/science.aaq0216 **This study provides the first global harmonized database on the variation of food's impacts on different steps in the supply chain, including five environmental indicators. The paper also provides an integrated mitigation framework of environmental impact of food systems and products from production to consumption.**
13. Dernini S, Berry EM, Vecchia C, La CR. Review article Med Diet 4.0: the Mediterranean diet with four sustainable benefits. Public Health Nutr. 2017:6–14. https://doi.org/10.1017/S1368980016003177.
14. Pelly F, Meyer NL, Pearce J, Burkhart SJ, Burke LM. Evaluation of food provision and nutrition support at the London 2012 Olympic Games: the opinion of sports nutrition experts. Int J Sport Nutr Exerc Metab [Internet]. 2014;24(6):674–83. https://doi.org/10.1123/ijsnem.2013-0218.
15. Meyer NL. Good food, health and sustainability: an introduction for health professionals. ACSM's Health & Fitness Journal. 2015;19(4):12–21. https://doi.org/10.1249/FIT.0000000000000136.
16.•• Meyer N, Reguant-Closa A. "Eat as if you could save the planet and win!" Sustainability integration into nutrition for exercise. Nutrients. 2017;9(412). https://doi.org/10.3390/nu9040412 **This concept paper provides the reader with an extensive overview of the integration of sustainability applicable to exercise and sports nutrition. The paper is divided into environmental impacts of the food system, sustainability and health duality, global integration of sustainability in dietary guidelines, and a practical section with focus on animal and plant proteins, diet diversity, and quality, with recommendations and tools to get started.**
17.• Reguant-Closa A, Harris MM, Lohman TG, Meyer NL. Validation of the Athlete's Plate Nutrition Educational Tool: phase I. Int J Sport Nutr Exerc Metab. 2019:1–26. https://doi.org/10.1123/ijsnem.2018-0346 **This validation of the Athlete's Plate Nutrition Education Tool identified higher protein proportions than recommended, mainly stemming from animal sources. This paper highlights the importance of integrating sustainability while maintaining health and performance when making recommendations for athletes.**
18.•• Lynch H, Johnston C, Wharton C. Plant-based diets: considerations for environmental impact, protein quality, and exercise performance. Nutrients. 2018;10(12). https://doi.org/10.3390/nu10121841 **This review examines the impact of plant-based diets on physical health, environmental sustainability, and exercise performance. Plant-based diets do not seem to provide advantages or disadvantages on exercise performance, but plant-based diets can reduce the risk of chronic disease and have a lower environmental impact.**
19.• Burd NA, CF MK, Salvador AF, KJM P, Moore DR. Dietary protein quantity, quality, and exercise are key to healthy living: a muscle-centric perspective across the lifespan. Front Nutr. 2019;6:83. https://doi.org/10.3389/fnut.2019.00083 **This paper discusses protein recommendations for physical activity through the lifespan. The paper highlights the importance of protein quantity, quality, and timing for exercise but includes a vision for protein as a component of a whole food approach, where interactions with other foods can affect muscle mass at different life stages.**
20. Burke LM, Hawley JA, Wong SHS, Jeukendrup AE. Carbohydrates for training and competition. J Sports Sci. 2011;29(Suppl 1):S17–27. https://doi.org/10.1080/02640414.2011.585473.
21. Phillips SM, Van Loon LJC. Dietary protein for athletes: from requirements to optimum adaptation. J Sports Sci. 2011;29(sup1):S29–38. https://doi.org/10.1080/02640414.2011.619204.
22. Thomas DT, Erdman KA, Burke LM. Nutrition and athletic performance. Med Sci Sports Exerc. 2016;48(3):543–68. https://doi.org/10.1249/MSS.0000000000000852.
23. Della Guardia L, Cavallaro M, Cena H. The risks of self-made diets: the case of an amateur bodybuilder. J Int Soc Sports Nutr. 2015;12(1):16. https://doi.org/10.1186/s12970-015-0077-8.
24. Spendlove J, Mitchell L, Gifford J, Hackett D, Slater G, Cobley S, et al. Dietary intake of competitive bodybuilders. Sports Med. 2015;45(7):1041–63. https://doi.org/10.1007/s40279-015-0329-4.
25. Lohman R, Carr A, Condo D. Nutritional intake in Australian football players: sports nutrition knowledge and macronutrient and micronutrient intake. Int J Sport Nutr Exerc Metab. 2019;29(3):289–96. https://doi.org/10.1123/ijsnem.2018-0031.
26. Lis D, Stellingwerff T, Shing CM, Ahuja KDK, Fell J. Exploring the popularity, experiences and beliefs surrounding gluten-free diets in non-coeliac athletes. Int J Sport Nutr Exerc Metab. 2015;25(1):37–45. https://doi.org/10.1123/ijsnem.2013-0247.
27. Lis DM, Kings D, Larson-Meyer DE. Dietary practices adopted by track-and-field athletes: gluten-free, low FODMAP, vegetarian, and fasting. Int J Sport Nutr Exerc Metab [Internet]. 2019;29(2):236–45. https://doi.org/10.1123/ijsnem.2018-0309.
28. Jovanov P, Đorđić V, Obradović B, Barak O, Pezo L, Marić A, et al. Prevalence, knowledge and attitudes towards using sports supplements among young athletes. J Int Soc Sports Nutr. 2019;16(1):27. https://doi.org/10.1186/s12970-019-0294-7.
29. Madden R, Shearer J, Parnell J. Evaluation of dietary intakes and supplement use in paralympic athletes. Nutrients. 2017;9(11):1266. https://doi.org/10.3390/nu9111266.
30. Abbey EL, Wright CJ, Kirkpatrick CM. Nutrition practices and knowledge among NCAA Division III football players. J Int Soc Sports Nutr. 2017;14:13. https://doi.org/10.1186/s12970-017-0170-2.
31. Garnett T. Plating up solutions. Science. 2016;353(6305):1202–1204. https://doi.org/10.1126/science.aah4765
32. Falcone G, Iofrida N, Stillitano T, De Luca AI. Impacts of food and diets' life cycle: a brief review. Curr Opin Environ Sci Heal. 2020;13:75–9. https://doi.org/10.1016/J.COESH.2019.12.002.
33. Nemecek T, Jungbluth N, Canals LM, Schenck R. Environmental impacts of food consumption and nutrition: where are we and what is next? Int J Life Cycle Assess. 2016;21:607–20. https://doi.org/10.1007/s11367-016-1071-3.
34. Fraval S, van Middelaar CE, Ridoutt BG, Opio C. Life cycle assessment of food products. In: Encyclopedia of food security and sustainability: Elsevier; 2019. p. 488–96. https://doi.org/10.1016/B978-0-08-100596-5.22221-X.
35. ISO 14040:2006. Environmental management - life cycle assessment - principles and framework. 2006.
36. Bystricky M, Alig M, Nemecek T, Gaillard G. Life-cycle assessment of Swiss agricultural products compared with imports. Agrar Schweiz. 2015;6:264–9.
37. Molina-Besch K, Wikström F, Williams H. The environmental impact of packaging in food supply chains—does life cycle

assessment of food provide the full picture? Int J Life Cycle Assess. 2019;24(1):37–50. https://doi.org/10.1007/s11367-018-1500-6.
38. Williams H, Wikström F. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. J Clean Prod. 2011;19(1):43–8. https://doi.org/10.1016/j.jclepro.2010.08.008.
39. Jones AD, Hoey L, Blesh J, Miller L, Green A, Shapiro LF. A systematic review of the measurement of sustainable diets. Adv Nutr An Int Rev J. 2016;7(4):641–64. https://doi.org/10.3945/an.115.011015.
40. Aleksandrowicz L, Green R, Joy EJM, Smith P, Haines A. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. PLoS One. 2016;11(11):1–16. Available from:. https://doi.org/10.1371/journal.pone.0165797.
41.• Chai BC, van der Voort JR, Grofelnik K, Eliasdottir HG, Klöss I, FJA P-C. Which diet has the least environmental impact on our planet? A systematic review of vegan, vegetarian and omnivorous diets. Sustainability. 2019;11(15):4110. https://doi.org/10.3390/su11154110 **This systematic review examines the environmental impact of vegan, vegetarian, and omnivorous diets. The results of this review suggest that a vegan diet has the lowest level of GhGe, water, and land use per 2000 kcal consumed.**
42. Hallström E, Carlsson-Kanyama A, Börjesson P. Environmental impact of dietary change: a systematic review. J Clean Prod. 2015;91:1–11. https://doi.org/10.1016/j.jclepro.2014.12.008.
43. Tilman D, Clark M. Global diets link environmental sustainability and human health. Nature. 2014;515(7528):518–22. https://doi.org/10.1038/nature13959.
44. Soret S, Mejia A, Batech M, Jaceldo-Siegl K, Harwatt H, Sabaté J. Climate change mitigation and health effects of varied dietary patterns in real-life settings throughout North America. Am J Clin Nutr. 2014;100(SUPPL. 1):490–5. https://doi.org/10.3945/ajcn.113.071589.
45. Baroni L, Cenci L, Tettamanti M, Berati M. Evaluating the environmental impact of various dietary patterns combined with different food production systems. Eur J Clin Nutr. 2007;61:279–86. https://doi.org/10.1038/sj.ejcn.1602522.
46. van de Kamp ME, van Dooren C, Hollander A, Geurts M, Brink EJ, van Rossum C, et al. Healthy diets with reduced environmental impact? – the greenhouse gas emissions of various diets adhering to the Dutch food based dietary guidelines. Food Res Int. 2018;104:14–24. https://doi.org/10.1016/j.foodres.2017.06.006.
47. Ridoutt BG, Hendrie GA, Noakes M. Dietary strategies to reduce environmental impact: a critical review of the evidence. Adv Nutr. 2017;8(6):933–46. https://doi.org/10.3945/an.117.016691.
48. Behrens P, Kiefte-de Jong JC, Bosker T, Rodrigues JFD, de Koning A, Tukker A. Evaluating the environmental impacts of dietary recommendations. Proc Natl Acad Sci U S A. 2017;114(51):13412–7. https://doi.org/10.1073/pnas.1711889114.
49. Mertens E, Kuijsten A, van Zanten HH, Kaptijn G, Dofková M, Mistura L, et al. Dietary choices and environmental impact in four European countries. J Clean Prod. 2019;237:117827. https://doi.org/10.1016/J.JCLEPRO.2019.117827.
50. Walker C, Gibney ER, Mathers JC, Hellweg S. Comparing environmental and personal health impacts of individual food choices. Sci Total Environ. 2019;685:609–20. https://doi.org/10.1016/j.scitotenv.2019.05.404.
51. Heller MC, Willits-Smith A, Meyer R, Keoleian GA, Rose D. Greenhouse gas emissions and energy use associated with production of individual self-selected US diets. Environ Res Lett. 2018;13(4):044004. https://doi.org/10.1088/1748-9326/aab0ac.
52. Van Kernebeek HRJ, Oosting SJ, Feskens EJM, Gerber PJ, De Boer IJM. The effect of nutritional quality on comparing environmental impacts of human diets. J Clean Prod. 2014;73:88–99. https://doi.org/10.1016/j.jclepro.2013.11.028.
53.• Saarinen M, Fogelholm M, Tahvonen R, Kurppa S. Taking nutrition into account within the life cycle assessment of food products. J Clean Prod. 2017;149:828–44. https://doi.org/10.1016/j.jclepro.2017.02.062 **This paper develops a methodology to include nutrition and environmental aspects when conducting life cycle assessment of food products. The study considers nutrients (individually or combined) as a functional unit, aiming to identify a process to categorize sustainable or unsustainable foods.**
54. Sonesson U, Davis J, Flysjö A, Gustavsson J, Witthöft C. Protein quality as functional unit – a methodological framework for inclusion in life cycle assessment of food. J Clean Prod. 2017;140:470–8. https://doi.org/10.1016/j.jclepro.2016.06.115.
55. Tessari P, Lante A, Mosca G. Essential amino acids: master regulators of nutrition and environmental footprint? Sci Rep. 2016;6:26074. https://doi.org/10.1038/srep26074.
56.•• Berardy A, Johnston CS, Plukis A, Vizcaino M, Wharton C. Integrating protein quality and quantity with environmental impacts in life cycle assessment. Sustainability. 2019;11:2747. https://doi.org/10.3390/su11102747 **This paper presents a novel approach to incorporate the Digestible Indispensable Amino Acid Score (DIAAS) to integrate protein quality and quantity (typical serving sizes) when comparing LCA data. The study proposes a new approach to evaluate nutrition and environmental sustainability of protein-rich foods and is thus critical for the field of sports nutrition.**
57. Conrad Z, Niles MT, Neher DA, Roy ED, Tichenor NE, Jahns L. Relationship between food waste, diet quality, and environmental sustainability. Marelli B, editor. PLoS One. 2018;13(4):e0195405. https://doi.org/10.1371/journal.pone.0195405.
58. Beretta C, Hellweg S. Potential environmental benefits from food waste prevention in the food service sector. Resour Conserv Recycl. 2019;147:169–78. https://doi.org/10.1016/j.resconrec.2019.03.023.
59. Stoessel F, Juraske R, Pfister S, Hellweg S. Life cycle inventory and carbon and water foodprint of fruits and vegetables: application to a swiss retailer. Environ Sci Technol. 2012;46(6):3253–62. https://doi.org/10.1021/es2030577.
60. Reynolds CJ. Energy embodied in household cookery: the missing part of a sustainable food system? Part 1: a method to survey and calculate representative recipes. In: B. G, S.A. T, editor. 1st International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF 2017. University of Sheffield, Department of Geography, Faculty of Social Sciences, Winter Street, Sheffield, S3 7ND. Oxford: Elsevier Ltd; 2017. p. 220–7. https://doi.org/10.1016/j.egypro.2017.07.245.
61. Canning P, Charles A, Huang S, Polenske KR, Waters A. Energy Use in the U.S. Food System. U.S. Dept of Agri, Econ Res Serv. 2010; (94).
62. Ahmad S, Wong KY, Ahmad R. Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects. Procedia Manuf. 2019;34:49–57. https://doi.org/10.1016/j.promfg.2019.06.113.
63. Arcand Y, Maxime D, Zareifard R. Life cycle assessment of processed food. Boston: Springer; 2012. p. 115–48.
64. Wunderlich SM, Feldman C, Kane S, Hazhin T. Nutritional quality of organic, conventional, and seasonally grown broccoli using vitamin C as a marker. Int J Food Sci Nutr. 2008;59(1):34–45. https://doi.org/10.1080/09637480701453637.
65. Batziakas KG, Talavera M, Swaney-Stueve M, Rivard CL, Pliakoni ED. Descriptive analysis and consumer acceptability of

locally and commercially grown spinach. J Food Sci. 2019;84(8):2261–8. https://doi.org/10.1111/1750-3841.14710.

66. Phillips KM, Tarrago-Trani MT, McGinty RC, Rasor AS, Haytowitz DB, Pehrsson PR. Seasonal variability of the vitamin C content of fresh fruits and vegetables in a local retail market. J Sci Food Agric. 2018;98(11):4191–204. https://doi.org/10.1002/jsfa.8941.
67. Macdiarmid JI. Seasonality and dietary requirements: will eating seasonal food contribute to health and environmental sustainability? Proc Nutr Soc. 2014;73:368–75. https://doi.org/10.1017/S0029665113003753.
68. van Zanten HHE, Mollenhorst H, Klootwijk CW, van Middelaar CE, de Boer IJM. Global food supply: land use efficiency of livestock systems. Int J Life Cycle Assess. 2016;21:747–58. https://doi.org/10.1007/s11367-015-0944-1.
69. Ertl P, Klocker H, Hörtenhuber S, Knaus W, Zollitsch W. The net contribution of dairy production to human food supply: the case of Austrian dairy farms. Agric Syst. 2015;137:119–25. https://doi.org/10.1016/j.agsy.2015.04.004.
70. de Vries M, de Boer IJM. Comparing environmental impacts for livestock products: a review of life cycle assessments. Livest Sci. 2010;128(1–3):1–11. https://doi.org/10.1016/J.LIVSCI.2009.11.007.
71. Bibbiani C, Fronte B, Incrocci L, Campiotti C. Life cycle impact of industrial aquaculture systems: a review. Calitatea. 2018;19(S1):67–71.
72. Malowany JM, West DWD, Williamson E, Volterman KA, Abou Sawan S, Mazzulla M, et al. Protein to maximize whole-body anabolism in resistance-trained females after exercise. Med Sci Sports Exerc. 2019;51(4):798–804. https://doi.org/10.1249/MSS.0000000000001832.
73. Gillen JB, West DWD, Williamson EP, Fung HJW, Moore DR. Low-carbohydrate training increases protein requirements of endurance athletes. Med Sci Sport Exerc. 2019;51(11):2294–301. https://doi.org/10.1249/MSS.0000000000002036.
74. Phillips SM. A brief review of higher dietary protein diets in weight loss: a focus on athletes. Sport Med. 2014;44:149–53. https://doi.org/10.1007/s40279-014-0254-y.
75. Witard OC, Garthe I, Phillips SM. Dietary protein for training adaptation and body composition manipulation in track and field athletes. Int J Sport Nutr Exerc Metab. 2019;29(2):165–74. https://doi.org/10.1123/ijsnem.2018-0267.
76. Murphy CH, Hector AJ, Phillips SM. Considerations for protein intake in managing weight loss in athletes. Eur J Sport Sci. 2015;15(1):21–8. https://doi.org/10.1080/17461391.2014.936325.
77. Hector A, Phillips SM. Protein recommendations for weight loss in elite athletes: a focus on body composition and performance. Int J Sport Nutr Exerc Metab. 2017;32:1–26. https://doi.org/10.1123/ijsnem.2017-0273.
78. Helms ER, Zinn C, Rowlands DS, Brown SR. A systematic review of dietary protein during caloric restriction in resistance trained lean athletes: a case for higher intakes. Int J Sport Nutr Exerc Metab. 2014;24(2):127–38. https://doi.org/10.1123/ijsnem.2013-0054.
79. Phillips SM. Current concepts and unresolved questions in dietary protein requirements and supplements in adults. Front Nutr. 2017;4:13. https://doi.org/10.3389/fnut.2017.00013.
80. Moore DR, Churchward-Venne TA, Witard O, Breen L, Burd NA, Tipton KD, et al. Protein ingestion to stimulate myofibrillar protein synthesis requires greater relative protein intakes in healthy older versus younger men. J Gerontol A Biol Sci Med Sci. 2015;70(1):57–62. https://doi.org/10.1093/gerona/glu103.
81. Atherton PJ, Etheridge T, Watt PW, Wilkinson D, Selby A, Rankin D, et al. Muscle full effect after oral protein: time-dependent concordance and discordance between human muscle protein synthesis and mTORC1 signaling. Am J Clin Nutr. 2010;92(5):1080–8. https://doi.org/10.3945/ajcn.2010.29819.
82. Areta JL, Burke LM, Ross ML, Camera DM, West DWD, Broad EM, et al. Timing and distribution of protein ingestion during prolonged recovery from resistance exercise alters myofibrillar protein synthesis. J Physiol. 2013;591(9):2319–31. https://doi.org/10.1113/jphysiol.2012.244897.
83.• Moore DR. Maximizing post-exercise anabolism: the case for relative protein intakes. Front Nutr. 2019;6:147. https://doi.org/10.3389/fnut.2019.00147 **This review highlights the importance to adjust protein recommendations dependent on individual body weight and advises an intake of 0.31 g kg^{-1} of high-quality protein after resistance training to maximize post-exercise muscle anabolism. The review highlights the need for further research on foods with suboptimal amino acid composition (e.g., plant-based) or chronic low energy intake among others.**
84. Witard OC, Jackman SR, Breen L, Smith K, Selby A, Tipton KD. Myofibrillar muscle protein synthesis rates subsequent to a meal in response to increasing doses of whey protein at rest and after resistance exercise. Am J Clin Nutr. 2014;99(1):86–95. https://doi.org/10.3945/ajcn.112.055517.
85. Tang JE, Moore DR, Kujbida GW, Tarnopolsky MA, Phillips SM. Ingestion of whey hydrolysate, casein, or soy protein isolate: effects on mixed muscle protein synthesis at rest and following resistance exercise in young men. J Appl Physiol. 2009;107(3):987–92. https://doi.org/10.1152/japplphysiol.00076.2009.
86. Res PT, Groen B, Pennings B, Beelen M, Wallis GA, Gijsen AP, et al. Protein ingestion before sleep improves postexercise overnight recovery. Med Sci Sports Exerc. 2012;44(8):1560–9. https://doi.org/10.1249/MSS.0b013e31824cc363.
87. Trommelen J, Kouw IWK, Holwerda AM, Snijders T, Halson SL, Rollo I, et al. Pre-sleep dietary protein-derived amino acids are incorporated in myofibrillar protein during post-exercise overnight recovery. Am J Physiol Metab. 2018;314(5):E457–67. https://doi.org/10.1152/ajpendo.00273.2016.
88.•• Burd NA, Beals JW, Martinez IG, Salvador AF, Skinner SK. Food-First approach to enhance the regulation of post-exercise skeletal muscle protein synthesis and remodeling. Sport Med. 2019;49(S1):59–68. https://doi.org/10.1007/s40279-018-1009-y **This review examines the potential interaction effects of the food matrix associated with dietary protein requirements. The paper highlights positive effects of a whole food approach benefiting skeletal muscle adaptive responses post exercise.**
89. Leser S. The 2013 FAO report on dietary protein quality evaluation in human nutrition: recommendations and implications. Nutr Bull. 2013;38(4):421–8. https://doi.org/10.1111/nbu.12063.
90. Norton LE, Layman DK. Leucine regulates translation initiation of protein synthesis in skeletal muscle after exercise. J Nutr. 2006;136(2):533S–7S. https://doi.org/10.1093/jn/136.2.533S.
91. Garlick PJ. The role of leucine in the regulation of protein metabolism. J Nutr. 2005;135(6 Suppl):1553S–6S. https://doi.org/10.1093/jn/135.6.1553S.
92. Macnaughton LS, Wardle SL, Witard OC, McGlory C, Hamilton DL, Jeromson S, et al. The response of muscle protein synthesis following whole-body resistance exercise is greater following 40 g than 20 g of ingested whey protein. Physiol Rep. 2016;4(15):1102–6. https://doi.org/10.14814/phy2.12893.
93. Rowlands DS, Nelson AR, Phillips SM, Faulkner JA, Clarke J, Burd NA, et al. Protein-leucine fed dose effects on muscle protein synthesis after endurance exercise. Med Sci Sports Exerc. 2014;47:547–55.
94. Phillips SM, Tang JE, Moore DR. The role of milk- and soy-based protein in support of muscle protein synthesis and muscle protein accretion in young and elderly persons. J Am Coll Nutr.

2009;28(4):343–54. https://doi.org/10.1080/07315724.2009.10718096.
95.•• van Vliet S, Beals JW, Martinez IG, Skinner SK, Burd NA. Achieving optimal post-exercise muscle protein remodeling in physically active adults through whole food consumption. Nutrients. 2018;10(2). https://doi.org/10.3390/nu10020224 **This review evaluates the efficacy of whole foods rich in nutrients and proteins to stimulate post-exercise muscle protein synthesis. The review highlights that whole foods can improve the overall diet quality and promote changes on muscle protein synthesis.**
96.•• SHM G, JJR C, JMG S, WAH W, Bierau J, Verdijk LB, et al. Protein content and amino acid composition of commercially available plant-based protein isolates. Amino Acids. 2018;50(12):1685–95. https://doi.org/10.1007/s00726-018-2640-5 **This study compared the essential amino acid concentrations of different plant-based protein isolates with animal-based proteins. The study provides an invaluable database of plant-based protein sources that when combined can provide similar amino acid concentrations as animal-based protein sources.**
97. Rutherfurd SM, Fanning AC, Miller BJ, Moughan PJ. Protein digestibility-corrected amino acid scores and digestible indispensable amino acid scores differentially describe protein quality in growing male rats. J Nutr. 2015;145(2):372–9. https://doi.org/10.3945/jn.114.195438.
98. Gorissen SH, Horstman AM, Franssen R, Crombag JJ, Langer H, Bierau J, et al. Ingestion of wheat protein increases in vivo muscle protein synthesis rates in healthy older men in a randomized trial. J Nutr. 2016;146(9):1651–9. https://doi.org/10.3945/jn.116.231340.
99. Food and Agriculture Organization of the United Nations. FAOSTAT. Food balance sheets. Rome, Italy; 2009. Available from: www.worldbank.com
100. Wardenaar F, Brinkmans N, Ceelen I, Van Rooij B, Mensink M, Witkamp R, et al. Macronutrient intakes in 553 dutch elite and sub-elite endurance, team, and strength athletes: does intake differ between sport disciplines? Nutrients. 2017;9(2). https://doi.org/10.3390/nu9020119.
101. Garcia-Rovés PM, Fernández S, Rodríguez M, Pérez-Landaluce J, Patterson AM. Eating pattern and nutritional status of international elite flatwater paddlers. Int J Sport Nutr Exerc Metab. 2000;10(2):182–98. https://doi.org/10.1123/ijsnem.10.2.182.
102. Bouvard V, Loomis D, Guyton KZ, Grosse Y, El Ghissassi F, Benbrahim-Tallaa L, et al. Carcinogenicity of consumption of red and processed meat. Lancet Oncol. 2015;16(16):1599–600. https://doi.org/10.1016/S1470-2045(15)00444-1.
103. Bianco A, Mammina C, Paoli A, Bellafiore M, Battaglia G, Caramazza G, et al. Protein supplementation in strength and conditioning adepts: knowledge, dietary behavior and practice in Palermo, Italy. J Int Soc Sports Nutr. 2011;8(1):25. https://doi.org/10.1186/1550-2783-8-25.
104. Garthe I, Maughan RJ. Athletes and supplements: prevalence and perspectives. Int J Sport Nutr Exerc Metab. 2018;28(2):126–38. https://doi.org/10.1123/ijsnem.2017-0429.
105. Cermak NM, Res PT, de Groot LC, Saris WH, van Loon LJ. Protein supplementation augments the adaptive response of skeletal muscle to resistance-type exercise training: a meta-analysis. Am J Clin Nutr. 2012;96(6):1454–64. https://doi.org/10.3945/ajcn.112.037556.
106. Baltazar-Martins G, Brito de Souza D, Aguilar-Navarro M, Muñoz-Guerra J, MDM P, Del Coso J. Prevalence and patterns of dietary supplement use in elite Spanish athletes. J Int Soc Sports Nutr. 2019;16(1):30. https://doi.org/10.1186/s12970-019-0296-5.
107. Whitehouse G, Lawlis T. Protein supplements and adolescent athletes: a pilot study investigating the risk knowledge, motivations and prevalence of use. Nutr Diet. 2017;74(5):509–15. https://doi.org/10.1111/1747-0080.12367.
108. Shaw G, Slater G, Burke LM. Changes in the supplementation practices of elite australian swimmers over 11 years. Int J Sport Nutr Exerc Metab. 2016;26(6):565–71. https://doi.org/10.1123/ijsnem.2016-0060.
109. Maughan RJ, Depiesse F, Geyer H, International Association of Athletics Federations. The use of dietary supplements by athletes. J Sports Sci. 2007;25(Suppl 1):S103–13. https://doi.org/10.1080/02640410701607395.
110. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, et al. IOC consensus statement: dietary supplements and the high-performance athlete. Br J Sports Med. 2018;52(7):439–55. https://doi.org/10.1136/bjsports-2018-099027.
111.•• Kårlund A, Gómez-Gallego C, Turpeinen AM, Palo-Oja OM, El-Nezami H, Kolehmainen M. Protein supplements and their relation with nutrition, microbiota composition and health: is more protein always better for sportspeople? Nutrients. 2019;11(4):1–19. https://doi.org/10.3390/nu11040829 **This review examines the effect of high-protein diets and supplements on nutrition, health, and intestinal microbiota in active and sedentary people. The authors caution against the use of high-protein diets and supplement to avoid negative impacts on intestinal health.**
112. Moreno-Pérez D, Bressa C, Bailén M, Hamed-Bousdar S, Naclerio F, Carmona M, et al. Effect of a protein supplement on the gut microbiota of endurance athletes: a randomized, controlled, double-blind pilot study. Nutrients. 2018;10(3). https://doi.org/10.3390/nu10030337.
113. Clarke SF, Murphy EF, O'Sullivan O, Lucey AJ, Humphreys M, Hogan A, et al. Exercise and associated dietary extremes impact on gut microbial diversity. Gut. 2014;63(12):1913–20. https://doi.org/10.1136/gutjnl-2013-306541.
114.•• Clark A, Mach N. Exercise-induced stress behavior, gut-microbiota-brain axis and diet: a systematic review for athletes. J Int Soc Sports Nutr. 2016;13(1):1–21. https://doi.org/10.1186/s12970-016-0155-6 **This systematic review evaluates the interaction between exercise-induced stress, gut microbiota, and effects on health and athletic performance. The review suggests that improving nutrition to promote gut microbiota diversity and function can help mitigate the impact of stress on the gastrointestinal tract, and this might positively affect health and performance.**
115. Manore MM, Patton-Lopez MM, Meng Y, Sung WS. Sport nutrition knowledge, behaviors and beliefs of high school soccer players. Nutrients. 2017;9(350):1–14. https://doi.org/10.3390/nu9040350.
116. Noll M, De Mendonça CR, Pereira L, Rosa DS, Silveira EA. Determinants of eating patterns and nutrient intake among adolescent athletes: a systematic review. 2017;16:1–11. https://doi.org/10.1186/s12937-017-0267-0.
117. Viner RT, Harris M, Berning JR, Meyer NL. Energy availability and dietary patterns of adult male and female competitive cyclists with lower than expected bone mineral density. Int J Sport Nutr Exerc Metab. 2015;25(6):594–602. https://doi.org/10.1123/ijsnem.2015-0073.
118. McKenzie Y, Bowyer R, Leach H, Guila P, Horobin J, O'Sullivan N, et al. British Dietetic Association systematic review and evidence-based practice guidelines for the dietary management of irritable bowel syndrome in adults (2016 update). J Hum Nutr Diet. 2016;29(5):549–75. https://doi.org/10.1111/jhn.12385.
119. Wilson PB. Nutrition behaviors, perceptions, and beliefs of recent marathon finishers. Phys Sportsmed. 2016;44(3):242–51. https://doi.org/10.1080/00913847.2016.1177477.
120. Anderson AS, Haynie KR, McMillan RP, Osterberg KL, Boutagy NE, Frisard MI, et al. Early skeletal muscle adaptations to short-term high-fat diet in humans before changes in insulin sensitivity.

Obesity (Silver Spring). 2015;23(4):720–4. https://doi.org/10.1002/oby.21031.
121. Rinninella E, Cintoni M, Raoul P, Lopetuso LR, Scaldaferri F, Pulcini G, et al. Food components and dietary habits: keys for a healthy gut microbiota composition. Nutrients. 2019;11(10). https://doi.org/10.3390/nu11102393.
122. Hall KD, Bemis T, Brychta R, Chen KY, Courville A, Crayner EJ, et al. Calorie for calorie, dietary fat restriction results in more body fat loss than carbohydrate restriction in people with obesity. Cell Metab. 2015;22(3):427–36. https://doi.org/10.1016/j.cmet.2015.07.021.
123. Rolls BJ, Roe LS, Beach AM, Kris-Etherton PM. Provision of foods differing in energy density affects long-term weight loss. Obes Res. 2005;13(6):1052–60.
124. Domínguez R, Cuenca E, Maté-Muñoz JL, García-Fernández P, Serra-Paya N, Estevan MCL, et al. Effects of beetroot juice supplementation on cardiorespiratory endurance in athletes. A systematic review. Nutrients. 2017;9(1). https://doi.org/10.3390/nu9010043.
125. Bowtell JL, Sumners DP, Dyer A, Fox P, Mileva KN. Montmorency cherry juice reduces muscle damage caused by intensive strength exercise. Med Sci Sports Exerc. 2011;43(8):1544–51. https://doi.org/10.1249/MSS.0b013e31820e5adc.
126. Ince D, Sönmez G, Ince M. Effects of garlic on aerobic performance. Turk L Med Sci. 1999;30:557–61.
127. Burd NA, Gorissen SH, van Vliet S, Snijders T, van Loon LJ. Differences in postprandial protein handling after beef compared with milk ingestion during postexercise recovery: a randomized controlled trial. Am J Clin Nutr. 2015;102(4):828–36. https://doi.org/10.3945/ajcn.114.103184.
128. Kanda A, Nakayama K, Sanbongi C, Nagata M, Ikegami S, Itoh H. Effects of whey, caseinate, or milk protein ingestion on muscle protein synthesis after exercise. Nutrients. 2016;8(6):339. https://doi.org/10.3390/nu8060339.
129. Moore DR, Robinson MJ, Fry JL, Tang JE, Glover EI, Wilkinson SB, et al. Ingested protein dose response of muscle and albumin protein synthesis after resistance exercise in young men. Am J Clin Nutr. 2009;89(1):161–8. https://doi.org/10.3945/ajcn.2008.26401.
130. Pennings B, Boirie Y, Senden JM, Gijsen AP, Kuipers H, van Loon LJ. Whey protein stimulates postprandial muscle protein accretion more effectively than do casein and casein hydrolysate in older men. Am J Clin Nutr. 2011;93(5):997–1005. https://doi.org/10.3945/ajcn.110.008102.
131. Churchward-Venne T, Pinckaers P, Smeets J, Peeters W, Zorenc AH, Schierbeek H, et al. Myofibrillar and mitochondrial protein synthesis rates do not differ in young men following the ingestion of carbohydrate with milk protein, whey, or micellar casein after concurrent resistance- and endurance-type exercise. J Nutr. 2019;149(2):210–20. https://doi.org/10.1093/JN/NXY251.
132. Babault N, Païzis C, Deley G, Guérin-Deremaux L, Saniez M-H, Lefranc-Millot C, et al. Pea proteins oral supplementation promotes muscle thickness gains during resistance training: a double-blind, randomized, placebo-controlled clinical trial vs. whey protein. J Int Soc Sports Nutr. 2015;12(1):3. https://doi.org/10.1186/s12970-014-0064-5.
133. Elliot TA, Cree MG, Sanford AP, Wolfe RR, Tipton KD. Milk ingestion stimulates net muscle protein synthesis following resistance exercise. Med Sci Sports Exerc. 2006;38(4):667–74. https://doi.org/10.1249/01.mss.0000210190.64458.25.
134. van Vliet S, Shy EL, Abou Sawan S, Beals JW, West DW, Skinner SK, et al. Consumption of whole eggs promotes greater stimulation of postexercise muscle protein synthesis than consumption of isonitrogenous amounts of egg whites in young men. Am J Clin Nutr. 2017;106(6):1401–12. https://doi.org/10.3945/ajcn.117.159855.
135. Beis LY, Willkomm L, Ross R, Bekele Z, Wolde B, Fudge B, et al. Food and macronutrient intake of elite Ethiopian distance runners. J Int Soc Sports Nutr. 2011;8:7. https://doi.org/10.1186/1550-2783-8-7.
136. Eliud Kipchoge Breaks Two-Hour Marathon Barrier - The New York Times. Available from: https://www.nytimes.com/2019/10/12/sports/eliud-kipchoge-marathon-record.html (accessed 20 March 2020).
137. Tigchelaar M, Battisti DS, Naylor RL, Ray DK. Future warming increases probability of globally synchronized maize production shocks. Proc Natl Acad Sci U S A. 2018;115(26):6644–9. https://doi.org/10.1073/pnas.1718031115.
138. Taub DR, Miller B, Allen H. Effects of elevated CO_2 on the protein concentration of food crops: a meta-analysis. Glob Chang Biol. 2008;14(3):565–75. https://doi.org/10.1111/j.1365-2486.2007.01511.x.
139. van Vliet S, Burd NA, van Loon LJ. The skeletal muscle anabolic response to plant- versus animal-based protein consumption. J Nutr. 2015;145(9):1981–91. https://doi.org/10.3945/jn.114.204305.
140. Churchward-Venne TA, Pinckaers PJM, van Loon JJA, van Loon LJC. Consideration of insects as a source of dietary protein for human consumption. Nutr Rev. 2017;75(12):1035–45. https://doi.org/10.1093/nutrit/nux057.
141.• Derbyshire EJ. Flexitarian diets and health: a review of the evidence-based literature. Front Nutr. 2017;3:1–8. https://doi.org/10.3389/fnut.2016.00055 **This review focuses on the benefits of a flexitarian diet on health, highlighting its positive effects on body weight, metabolic health, and type 2 diabetes prevention. The paper also underlines gender differences and female's greater willingness to adhere to a flexitarian diet than males. Thus, males are becoming an important target for flexitarian diet interventions.**
142. The Culinary Institute of America, Harvard School of Public Health. The protein flip. 2016 [accessed 2016 Oct 10]. Available from: http://www.menusofchange.org/images/uploads/pdf/CIA_The_Protein_Flip_C_FINAL_6-17-15.pdf
143. Nieman DC. Physical fitness and vegetarian diets: is there a relation? Am J Clin Nutr. 1999;70(3 Suppl):570S–5S.
144. Grandjean AC. The vegetarian athlete. Phys Sportsmed. 1987;15(5):191–4. https://doi.org/10.1080/00913847.1987.11709361.
145. Reynlods G. Ask well: can athletes be vegan? New York Times 2014;D6. [accessed 2019 Oct 20]. Available from: https://well.blogs.nytimes.com/2014/11/24/ask-well-can-athletes-be-vegans/?searchResultPosition=1&mtrref=www.nytimes.com&gwh=C757295563 2CCEFB44269F3D164FF96A&gwt=pay&assetType=REGIWALL
146. Nebl J, Schuchardt JP, Ströhle A, Wasserfurth P, Haufe S, Eigendorf J, et al. Micronutrient status of recreational runners with vegetarian or non-vegetarian dietary patterns. Nutrients. 2019a;11(5):1146. https://doi.org/10.3390/nu11051146.
147. Nebl J, Haufe S, Eigendorf J, Wasserfurth P, Tegtbur U, Hahn A. Exercise capacity of vegan, lacto-ovo-vegetarian and omnivorous recreational runners. J Int Soc Sports Nutr. 2019b;16(1):23. https://doi.org/10.1186/s12970-019-0289-4.
148. Craddock JC, Probst YC, Peoples GE. Vegetarian and omnivorous nutrition - comparing physical performance. Int J Sport Nutr Exerc Metab. 2016;26(3):212–20. https://doi.org/10.1123/ijsnem.2015-0231.
149. Melina V, Craig W, Levin S. Position of the academy of nutrition and dietetics: vegetarian diets. J Acad Nutr Diet. 2016;116(12):1970–80. https://doi.org/10.1016/j.jand.2016.09.025.
150. Kniskern MA, Johnston CS. Protein dietary reference intakes may be inadequate for vegetarians if low amounts of animal protein are

consumed. Nutrition. 2011;27(6):727–30. https://doi.org/10.1016/j.nut.2010.08.024.
151. Ciuris C, Lynch HM, Wharton C, Johnston CS. A comparison of dietary protein digestibility, based on DIAAS scoring, in vegetarian and non-vegetarian athletes. Nutrients. 2019;11(12):3016. https://doi.org/10.3390/nu11123016.
152. Lynch H, Wharton C, Johnston C. Cardiorespiratory fitness and peak torque differences between vegetarian and omnivore endurance athletes: a cross-sectional study. Nutrients. 2016;8(11):726. https://doi.org/10.3390/nu8110726.
153. Dawson A. These 19 elite athletes are vegan- here's what made them switch their diet. Business Insider. Available online: https://www.businessinsider.com/vegan-athetes-and-why-they-changed-their-diet-11 (accessed on 27 March 2020).
154. Kwok CS, Umar S, Myint PK, Mamas MA, Loke YK. Vegetarian diet, Seventh Day Adventists and risk of cardiovascular mortality: a systematic review and meta-analysis. Int J Cardiol. 2014;176(3):680–6. https://doi.org/10.1016/j.ijcard.2014.07.080.
155. Dinu M, Abbate R, Gensini GF, Casini A, Sofi F. Vegetarian, vegan diets and multiple health outcomes: a systematic review with meta-analysis of observational studies. Crit Rev Food Sci Nutr. 2017;57(17):3640–9. https://doi.org/10.1080/10408398.2016.1138447.
156. Satija A, Bhupathiraju SN, Rimm EB, Spiegelman D, Chiuve SE, Borgi L, et al. Plant-based dietary patterns and incidence of type 2 diabetes in US men and women: results from three prospective cohort studies. PLoS Med. 2016;13(6):e1002039. https://doi.org/10.2105/AJPH.2016.303046.
157. Sabaté J, Harwatt H, Soret S. Environmental nutrition: a new frontier for public health. Am J Public Health. 2016;106(5):815–21.
158. Orlich MJ, Fraser GE. Vegetarian diets in the Adventist Health Study 2: a review of initial published findings. Am J Clin Nutr. 2014;100(Suppl 1(1)):353S–8S. https://doi.org/10.3945/ajcn.113.071233.
159. Burkert NT, Muckenhuber J, Großschädl F, Rásky E, Freidl W. Nutrition and health - the association between eating behavior and various health parameters: a matched sample study. PLoS One. 2014;9(2):e88278. https://doi.org/10.1371/journal.pone.0088278.
160. Ferdowsian HR, Barnard ND. Effects of plant-based diets on plasma lipids. Am J Cardiol. 2009;104(7):947–56. https://doi.org/10.1016/j.amjcard.2009.05.032.
161. Szeto YT, Kwok TCY, Benzie IFF. Effects of a long-term vegetarian diet on biomarkers of antioxidant status and cardiovascular disease risk. Nutrition. 2004;20(10):863–6. https://doi.org/10.1016/j.nut.2004.06.006.
162. Wang F, Zheng J, Yang B, Jiang J, Fu Y, Li D. Effects of vegetarian diets on blood lipids: a systematic review and meta-analysis of randomized controlled trials. J Am Heart Assoc. 2015;4(10):e002408. https://doi.org/10.1161/JAHA.115.002408.
163.•• Barnard N, Goldman D, Loomis J, Kahleova H, Levin S, Neabore S, et al. Plant-based diets for cardiovascular safety and performance in endurance sports. Nutrients. 2019;11(1):130. https://doi.org/10.3390/nu11010130 **This review explores the health and performance benefits of plant-based diets on endurance athletes. The review highlights possible positive effects, such as weight control, higher antioxidants due to fruit and vegetable content, higher glycogen stores due to high carbohydrate intakes, and improved cardiovascular and metabolic parameters.**
164. Cialdella-Kam L, Kulpins D, Manore M. Vegetarian, gluten-free, and energy restricted diets in female athletes. Sports. 2016;4(4):50. https://doi.org/10.3390/sports4040050.
165. Mujika I. Case study: long-term low-carbohydrate, high-fat diet impairs performance and subjective well-being in a world-class vegetarian long-distance triathlete. Int J Sport Nutr Exerc Metab. 2019;29(3):339–44. https://doi.org/10.1123/IJSNEM.2018-0124.
166. Wirnitzer K, Boldt P, Lechleitner C, Wirnitzer G, Leitzmann C, Rosemann T, et al. Health status of female and male vegetarian and vegan endurance runners compared to omnivores—results from the NURMI study (step 2). Nutrients. 2018;11(1):29. https://doi.org/10.3390/nu11010029.
167. Boldt P, Knechtle B, Nikolaidis P, Lechleitner C, Wirnitzer G, Leitzmann C, et al. Quality of life of female and male vegetarian and vegan endurance runners compared to omnivores – results from the NURMI study (step 2). J Int Soc Sports Nutr. 2018;15(1):33. https://doi.org/10.1186/s12970-018-0237-8.
168. Walsh NP. Nutrition and athlete immune health: new perspectives on an old paradigm. Sport Med. 2019;49(S2):153–68. https://doi.org/10.1007/s40279-019-01160-3.
169. Rodriguez NR, DiMarco NM, Langley S. Position of the American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. J Am Diet Assoc. 2009;109(3):509–27.
170. Gilani GS, Cockell AK, Sepehr E. Effects of antinutritional factors on protein digestibility and amino acid availability in foods. J AOAC Int. 2005;88(3):967–87. https://doi.org/10.1093/jaoac/88.3.967.
171. Ekpa O, Palacios-Rojas N, Kruseman G, Fogliano V, Linnemann AR. Sub-Saharan African maize-based foods: technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. Glob Food Sec. 2018;17:48–56. https://doi.org/10.1016/J.GFS.2018.03.007.
172. Gobbetti M, De Angelis M, Di Cagno R, Calasso M, Archetti G, Rizzello CG. Novel insights on the functional/nutritional features of the sourdough fermentation. Int J Food Microbiol. 2019;302(5):103–13. https://doi.org/10.1016/j.ijfoodmicro.2018.05.018.
173. Ingram J, Ajates R, Arnall A, Blake L, Borrelli R, Collier R, et al. A future workforce of food-system analysts. Nat Food. 2020;1(1):9–10. https://doi.org/10.1038/s43016-019-0003-3 **This concept paper illustrates the shift needed in knowledge, understanding, skills, and values when working with the current food system. Systems thinking and multi-disciplinary actions are needed also in sports nutrition.**
174. Meyer N. Transforming food journeys on a college campus: discourse from the frontlines of food and farming. J Food Nutr Sci. 2019;1(3):128–38. https://doi.org/10.1057/jfns000017.
175.• Wegener J. Equipping future generations of registered dietitian nutritionists and public health nutritionists: a commentary on education and training needs to promote sustainable food systems and practices in the 21st century. J Acad Nutr Diet. 2018;118(3):393–8. https://doi.org/10.1016/j.jand.2017.10.024 **This commentary paper illustrates the current gaps, challenges, and opportunities for nutrition professionals when integrating sustainable food systems into professional practice.**
176. Truman E, Lane D, Elliott C. Defining food literacy: a scoping review. Appetite. 2017;116:365–71. https://doi.org/10.1016/j.appet.2017.05.007.
177. Vidgen HA, Gallegos D. Defining food literacy and its components. Appetite. 2014;76:50–9. https://doi.org/10.1016/j.appet.2014.01.010.
178. Rowat AC, Soh M, Malan H, Jensen L, Schmidt L, Slusser W. Promoting an interdisciplinary food literacy framework to cultivate critical citizenship. J Am Coll Heal. 2019:1–4. https://doi.org/10.1080/07448481.2019.1679149.
179. International Olympic Committee. Olympic Movement's Agenda 21. 1999. Available from: http://www.olympic.org (accessed October 9 2019).
180. Food vision for the London 2012 Olympic Games and Paralympic Games. London; 2009. Available from: http://learninglegacy.

independent.gov.uk/documents/pdfs/sustainability/cp-london-2012-food-vision.pdf (accessed November 20 2018).
181. Rio Food Vision Diagnostic analysis for the supply of healthy and sustainable food for the 2016 Rio Olympic and Paralympic Games. Rio de Janeiro; 2014. Available from: www.riofoodvision.org (accessed September 17 2019).
182. Pelly F, Parker SS. Food provision at the Rio 2016 Olympic Games: expert review and future recommendations. Int J Sport Nutr Exerc Metab. 2019:1–6. https://doi.org/10.1123/ijsnem.2018-0175.
183. Green Sports Alliance. Available from: http://greensportsalliance.org/ (accessed February 6 2020).
184. Sports for Climate Action | UNFCCC. Available from: https://unfccc.int/climate-action/sectoral-engagement/sports-for-climate-action (accessed April 1 2020).
185. Mervosh S. Seaweed pods, anyone? Marathons get creative to stop littering the streets. The New York Times. 2019; Available from: https://www.nytimes.com/2019/04/30/sports/marathons-plastic-water-bottles.html (accessed March 27 2020).
186. Resource management report. Available from: https://tokyo2020.org/en/games/sustainability/asset (accessed April 1 2020).
187. International Ski Mountaineering Federation. ISMF sustainability handbook. Available online: www.ismf-ski.org (accessed on 1 April 2020).

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