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REVIEW ARTICLE

Vegan Diet in Sports and Exercise – Health Benefits and Advantages to Athletes and Physically Active People: A Narrative Review

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Abstract

Health is one factor in leading a fulfilled life. Since food and sport are considered to be 'medicines', their continuous inter-related application is a highly effective but simple tool for improving individual health. However, being a healthy human is a prerequisite for becoming a successful athlete. Vegan diets are booming in the mainstream and in sport. From current sporting success all the way back to ancient times, it is evident that vegans can win races up to professional levels and even break records. However, despite the sound health benefits of vegan diets, vegan athletes are frequently faced with prejudice on unsubstantiated grounds. Therefore, this review considers the various advantages of the vegan diet for young and competitive athletes. It encompasses early studies and compares the potential benefits and risks by looking at the quality of animal and plant protein. The knowledge that vegan diets are compatible with sports performance has the potential to encourage athletes and their families, coaches, and experts in health and sports to be more open-minded when an athlete expresses his/her desire to adopt a vegan diet. A short outline of the future perspectives of research needed is given.

Keywords

Sport, Physical exercise, Physical education, Vegan, Vegetarian, Plant-based, Health

Introduction

Health is a prerequisite for and one factor in leading a fulfilled life, and is also recognized as a fundamental social value [1] (p. 125). Moreover, it is the major prerequisite for a good fitness level and sporting success [2] (p. 401). The close connection between health and the lifestyle factors of nutrition and sport and exercise is considered to be undisputed. However, since food and sports are both considered 'medicine' [3-5] (p. 23), [6] (pp. 9-14, 38, 100) their continuous inter-related application is a highly effective but simple tool for improving individual health, especially for athletes. Moreover, because personal behavior (eg. food choices) has the greatest potential to harm or heal (40 %) [7] the athlete has the most impact on one´s state of health, whether for good or ill [2,7,8] (p. 409).

The concept of vegetarian or vegan diets had been firmly linked to sports and exercise even in ancient history [2] (pp. 409, 420, 423). However, since 2017 there has been a higher frequency of publication of review articles on veganism in sports than ever before, which all contribute to and reflect the increasingly high scientific interest in the linkages between a vegan diet and sport and exercise.

Within a timeframe of 16 years, between 2004 and 2020, nine review articles considering plant-based diets in relation to sports have been released [9-18], with five additionally focused on vegetarian diets or to a lesser

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extent on vegan diets [11,13,14,16-18], summarizing the little information available. These reviews were mainly based on studies performed on vegetarian non-active populations or athletes, with five focusing on nutritional considerations [9-11,13,14], and five addressing sports performance [12,15,16,18]. However, except for Fuhrman and Ferreri [11] who were the first to share their experiences of working with vegan athletes, none of the authors have published original research considering veganism and sport or have shown evidence of knowledge or experience of supervising vegan athletes. In addition, no review has addressed the most basic prerequisite for athletic (peak) performance, which is health above all. Additionally, data on veganism connected to sports and health has been published from our laboratory [2,19-25].

Therefore, the goal of this review is to consider the various health benefits resulting from a vegan diet to athletes and the concept that it might provide advantages for (young, competitive) athletes. In presenting relevant information for both experts and practitioners in the field of sports and physical education, the author has two decades of experience working with athletes of all performance levels and advising them how to switch to and to maintain a healthy, needs-based vegan diet. To the best of the author´s knowledge, this review is the first to provide a special perspective which cuts across the three disciplines of diet, sports and health. This review is also the first to combine scientific rationale from evidence-based data with relevant anecdotal information in order to support a more healthy approach to sports nutrition counseling of athletes. Based on this solid foundation, the intention is to nudge experts, ranging from sports practitioners such as coaches, dietitians and families to specialized scientists in the fields of sports, nutrition, medicine and health, to be more open-minded and not to reject out of hand an athlete's expressed desire to switch to a healthier dietary pattern, including a vegan diet.

Background

Nowadays, giving up meat and animal products is a steadily growing trend, mainly in industrialized nations, with the vegan diet (no foods from animals sources) being part of the vegan lifestyle (no products from animal origin at all) [26,27] (pp. 7, 12). Vegan diets not only constitute a current boom with increasing acceptance and appreciation amongst the public [28-30], but the numbers of vegetarians and vegans are also increasing in sports, including several famous athletes at world class level. Therefore, it is likely that the number of vegan athletes is rising across all fitness levels in school, recreational, amateur and professional sports.

The book *Thrive: The Vegan Nutrition Guide to Optimal Performance in Sports and Life* and the documentary *The Game Changers* are not only titles of well known bestsellers, but also reflect a current movement towards plant-based diets in the public and in sports around the globe while being much debated among sport scientists and sports nutrition experts at the same time.

On a global basis, the numbers of vegetarians and vegans have been growing at even faster rates than had once been anticipated [26,31,32]. 6% of the US populations are vegetarian (4.3 million) and vegan (3.7 million) [33]. About 10% of Europeans (75 million) adhere to some kind of vegetarian diet [34], with 10% of the Austrian (880,000), German (8.7 million), and Italian (1.2 million) populations [35-37], 13% of the British [38] and 14% of the Swiss population (1.2 million) [39] now identifying themselves as vegetarian or vegan. Moreover, the vegetarian and vegan lifestyles are relevant especially for the peer-groups of younger generations, with the so-called "millenials" (or "Generation Y", young adults: 22-38 years) as key of the current movement in the public and main drivers for the global avoidance of meat and increased trend towards plant-based diets [29,30]: 25% of 25-34 yr-aged in USA refer to themselves as vegetarian or vegan [29]; 25% of the 18 yr-aged in the UK eat vegetarian or vegan [40,41] while 30% of 18-24 yr-aged Brits have already considered to eat vegan or are already vegan [42]. Furthermore, 44% of Generation Z (young people < 24) rate the vegetarian and vegan lifestyles as cooler than smoking [43], 1 out of 12 parents in the UK (8.3% of 2.200) raise their children (0-12 yrs.) vegan due to health benefits as the main reason (61%) [44], and increasing numbers of the Baby Boomers generation at the age of 55+ yrs in the USA are going vegan mainly due to health [45].

Based on the background numbers of 10-44% vegetarians and 1-17% vegans [33,38,42,43,46], there would be 2-8 vegetarians and 1-4 vegans in any group of about 20 people (eg. a class of pupils or students, employees in a company or department, and even team-mates in a sports team). As a consequence, it is very likely that there is no longer any social group or sports team without a vegan person or athlete. Unpublished data from our laboratory considering the NURMI Study (Step 1) shows the prevalence of 35% vegans (n = 1.029), 21% vegetarians (n = 615) and 44% omnivores (44%, n = 1.315) starting in running events.

There are some professional vegan athletes who are active in endurance disciplines, such as Fiona Oakes (ultra-marathon running, set her fourth world record in 2018); Scott Jurek (ultra-marathon running, has set multiple records including the speed record for completing the Appalachian Trail of approximately 2,200 miles in 46 days, 8 hours, 7 minutes in 2015); Rich Roll (five-time Ultra Ironman triathlete); or Gerlinde Kaltenbrunner (the most successful female mountaineer in the world, has climbed all 14 eight-thousanders without supplementary oxygen or the help of porters). While Novak Djokovic (Number 1 in the 2018 ATP ranking list, 14-times Grand Slam winner, eg. Wimbledon, Australian Open) and Serena Williams (Number 16 in the 2018 ATP World ranking list, 23-times Grand Slam winner, eg. Wimbledon, Australian Open, French Open, US Open) are role models for vegan tennis athletes, others are representatives of technical sports, such as Meagan Duhamel (pairs figure skating; double Olympic champion, Pyeong Chang 2018; Olympic silver medal, Sochi 2014), power and strength disciplines, such as Patrik Baboumian (three-time world record holder at Beer Barrel Lift; Front Hold 20 kg; Yoke-walk 555.2 kg over 10 m in 2013, topped to 560 kg in 2015); Patrick Reiser (world champion Natural Bodybuilding); Kendrick Farris (Olympic Weight Lifter, Rio 2016; set the American record in the 94 kg weight class); or Frank Medrano (Superhuman Bodyweight Workout domination), and even in Formula 1, such as Lewis Hamilton (won the Formula 1 World Championship in 2019 for the sixth time). Even in team sports such as ice hockey, basketball and soccer (Forest Green Rovers, UK, were the first vegan football club), more and more athletes are following vegan diets, too. In addition, in 2014 in Brazil the German National Football Team won the World Championship while temporarily adopting a vegan diet.

These and numerous other successful athletes who adhere to vegan diets provide sufficient evidence that for all kinds of sports, ranging from high-level endurance and ultra-endurance to power and strength disciplines, athletic success (victories, world records, etc.) can be achieved when following a vegan diet. Therefore, it is reasonable to conclude that a vegan diet is compatible with peak performance in elite and professional sports.

Early studies on strict vegetarians and plant-based ancestors

The link between sports and exercise and a strict vegetarian (vegan) diet has been an area that has attracted scientific interest for more than 150 years (an overview is presented in Table 1) and is at present of growing importance. It can even be traced back to ancient times or early pre-history [2] (pp. 409, 420, 423).

The initial scientific interest in vegetarian diets as they relate to athletic performance emerged at the end of the 19th century [47,48], and at the beginning of the 20th century, resulted in the first studies conducted in this field. Different scientists investigated if and how vegetarian diets influence physical performance by conducting research at Belgium [49], Yale University Medical School [50-52], and Academie de Medicine de Paris [53], almost at the same time. Independent of each other, they found positive effects on exercise performance. These initial data comparing strict vegetarian athletes to meat-centered athletes (time to exhaustion: On a stationary bicycle, lifting an external load by handgrip meter, holding horizontal arm position, deep knee bends) can be summarized as containing two major findings [49-54]:

(1) Performances of vegetarian or vegan athletes were found to be two-fold to three-fold higher in terms of endurance, stamina and strength.

(2) Time needed for complete recovery was found to be markedly reduced in strict vegetarians, with some cases needing a fifth of the time that meat-eating athletes needed [49,53].

In the 1980s, over a seven-year period of field studies (1983-1990) consisting of several series of super-marathons, trekking tours at high altitudes, and desert traverses on foot [55] (pp. 18-20, 51-52, 60, 63-65, 159-174), [56] (pp.19-20), the potential that emerges from following strict vegetarian (vegan) diets was demonstrated, as well as the positive effects on physical performances resulting from Galina Schatalova's specific dietary concept for metabolic efficiency (minimal fluid and energy supply [55] (pp. 16, 51, 60, 64-65), [57] (pp. 17-18) and with whole plant foods [55] (p. 200). The endurance performance of the subjects of the experimental groups was reported as being better than those in the omnivorous control groups for all field trials [55] (p.161). The vegetarian hikers were better able to cope with severe physical stress and to sustain physical burdens, even at high altitudes and under extreme conditions [55] (pp. 164-172).

Together, these data indicate that strict vegetarians (vegans) are able to tolerate and even sustain higher physical burdens for longer durations, and to recover from physical stress more rapidly. This supports the assumption that vegetarian and vegan diets are compatible with peak performance sports Table 1 [20].

Back in ancient times, gladiators and philosophers knew that strict vegetarian (vegan) diets are compatible with physical and intellectual performances. Just to name one representative, the Greek Pythagoras was not only a prominent philosopher and mathematician, but an Olympic fist-fighter, too [2,58], (p. 423). In order to survive their fights in the arena, the gladiators had to be strong, skillful and persistent. Therefore, dietary schemes of fighters were aimed at keeping them effective and fit. The gladiators followed a specific diet ('gladiatoriam saginam' or even 'hordearii') that consisted of large amounts of legumes, pulses, and grains (78% from peas, lentils, barley, wheat, millet, corn), but explicitly with little or no meat. Based on archeological excavations, the gladiator´s intake of protein from animal origin has been demonstrated to be generally very small [58,59]. According to Longo, et al. [58] the best fighters in ancient times were vegetarian.

Dating back to even earlier in human evolution, dietary behavior and habits have been associated with physical and cognitive performance [2] (pp. 409-410). Based on Neanderthal ecology from genomic data showing regional differences, it has been suggested that human ancestors in prehistoric Spain (El Sidron cave)

Table 1: Overview of early studies on strict vegetarian (vegan) diets in sports.

Setting	Timeline	Studies & Results (in extracts, abbreviated)
Laboratory testing	1904-1907	1904 & 1907: Plant-based diets affecting physical performance (hand-grip meter, stationary bicycle) [50,51] ➢ Male subjects (students, fellow faculty members, and himself) ➢ Plant-based diet: Subjects exercised more, with less fatigue, vs. diet based on animal protein 1907: Series of tests (holding horizontal arm position, deep knee bends) comparing stamina and strength of meat eaters vs. vegetarians (Fisher's classic study) [52] ➢ Males, fed different diets, consecutively tested: Meat-eating athletes, vegetarian athletes, vegetarian sedentary subjects ➢ Compared to meat-eaters: Vegetarian athletes had twice the stamina, far more endurance ➢ Meat eating athletes: Outperformed even by vegetarian sedentary subjects ➢ Difference in endurance performance was entirely put down to diet ➢ Strong evidence: Vegetarian diets increase endurance
	1968	Fisher's classic study repeated (stationary bicycle to measure strength and endurance) [54]: ➢ Initially mixed diet (meat, vegetables) -> pedalling time until muscle failure: 114 min ➢ Re-test: High animal protein diet (rich in meat, milk, eggs) -> big drop in time: 57 min ➢ Final re-test: Strict vegetarian (vegan) diet (grains, vegetables, fruits; no animal foods) -> pedalling time: 167 min ➢ Vegan diet had: ❖ Three-times better performance than animal protein-centered ❖ One-third better performance than mixed diet
	1986-1992	2 laboratory studies [280,281] considering the physical performance of vegetarians, both comparing fitness of vegetarian to non-vegetarian athletes ➢ No differences in exercise performance
Field studies	1983-1990	Schatalova's 'Concept of Curative Healing', 'System of Natural Healing' [55] (pp. 18-20, 51-52, 60, 63-65, 159-174), [56] (pp. 19-20): 1983 - 1984: ➢ Series of 4 super-marathon races (500 km, 4-7 stages, 50-72 km/day, speed: 14-18 km/h) ➢ Series of mountain trekking tours ❖ Altitude of about 5,000 m (25 km/day) ❖ High altitude camp at 3,000 m altitude ❖ Foot march crossing 4 mountain passes over 23 days 1987-1990: ➢ Series of 4 expeditions of desert traverse on foot crossing Central Asian deserts (250-500 km, 30-35 km/day)
	1989	Deutschlandlauf 1987 [282-286]: Influence of a 1,000-km ultra-run on lipid metabolism, Western diet (n = 30) vs. wholesome vegetarian diet (n = 25) ➢ Runtime of vegetarians (114 h 14 min) was approximately 2 hours faster than that of omnivores (116 h 29 min) ➢ Use of medications and drugs, and need of medical supply, was less in vegetarians vs. controls/other ultra-runners
	1997	National Runners' Health Study (national US survey) [287]: Interactive effects of running (weekly mileage) and diet (weekly intakes of red meat, fish, fruit and alcohol), by self-reported food intakes of 289 vegetarians and 62 vegans, vs. physician-supplied medical data (8,891 omnivores) ➢ Compared to omnivores, vegetarians ran significantly further, had higher BMI, higher fruit intake, less alcohol ➢ Dietary assessment was limited -> lack of data on other foods/specific nutrients prevented any conclusion that red meat or fruit caused the associations

were vegetarians. Their meatless diet was characterized by mushrooms, pine nuts and moss [60]. In contrast, the Belgium Neanderthals (Spy cave) followed a heavily meat-centered diet [61,62].

Together, this shows that a meatless approach to physical performance is not new but rather is ancient knowledge that is currently being increasingly taken into account.

Sport alone is not enough to aid health and exercise performance

In sports, the goal has always been to excel over others and to outperform opponents, which is clearly represented by the saying 'higher, faster, further'.

After more than 50 years of epidemiological studies, it is accepted that cardiorespiratory fitness, which results from both healthy activity patterns and increased levels of sports and exercise, leads to better health [63]. A current study supports this by examining the effects of lifelong involvement in aerobic exercise (on average 52 years, exercising 7 h/week on 5 days/week) on cardiovascular and skeletal muscle health in 75-year-old subjects. The data show that substantial benefits emerge from a lifelong adherence to aerobic exercise. In addition to aerobic capacities 40% higher than their inactive age-matched peers, the active old subjects were calculated to have the cardiovascular health of people 30 years younger than themselves when compared to established data of capacities rated to be the norm [64].

It is generally accepted that sport and exercise are powerful tools that positively affect health and thus aid the prevention of severe illnesses [65]. Regular sport and exercise, at best on a daily basis, has been shown to be preventive in the development of chronic diseases, for example reducing the risk of coronary heart disease, stroke, diabetes, hypertension, and some cancers. Moreover, sport and exercise are key to balancing energy supply and utilization, and thus for controlling Body Weight (BW) [66].

However, physical activity, sport and exercise as a single mechanism for promoting individual health and aiding a healthy lifestyle are not enough, even when practiced outdoors. If that were true, farmers, gardeners, soldiers and others who have physically demanding jobs, which are to some extent outdoors (eg. professional athletes), would not get severely ill or suffer from (chronic) diseases. The following example exemplifies the fact that a 1-dimensional approach to health, especially for athletes, is limited.

The founder of the jogging movement, James Fuller Fixx, was convinced that non-smoking and sport were enough to ensure health and longevity, but that healthy eating was not important. However, he died from a heart attack during his daily jogging routine [67] (pp. 407-408). A current study has found that even well-trained and ambitious endurance athletes are at significant risk from atherosclerosis. Higher exercise-induced energy needs are usually covered by higher intakes of animal foods from a mixed diet, but the high intakes of saturated fats and cholesterol along with the lack of health-promoting items (eg. fiber, antioxidants) may contribute to arterial changes that promote atherosclerosis [16]. This might explain why endurance athletes more often develop severe atherosclerosis than non-active people (higher values for coronary plaque: 44% vs. 22% total [68], and (non-)calcified plaque [69,70]. Moreover, the carotid artery intima-media thickness has been found to be significantly higher in control groups following a typical non-vegetarian diet (0.74 mm) and even in endurance runners (0.63 mm), than in vegans (0.56 mm) [71,72]. Atherosclerosis can severely narrow not only the coronary arteries of soldiers and athletes by the age of about 20 years (75-90%) [69,73], but also the arteries of the brain and peripheral arteries of the upper and lower extremities, which consequently negatively affects athletic performance [16].

In this context, there is enormous potential to make an important contribution to the abandonment of the 1-dimensional perspective of health, whereby either one of these lifestyle factors is usually viewed and implemented in isolation, namely: *either* nutrition *or* sport and exercise [2] (pp. 418-419).

Dual guidelines on supporting good health have inextricably linked diet with sports and exercise recommendations since 2002. The goal has not only been to avoid unnecessary body fat accretion on a long-term basis through a balanced energy turnover, but also to promote and improve lifelong health and well-being, aiming to complement diet with activity guidelines compatible with reducing risk factors in order to prevent chronic diseases [2] (pp. 418-419). Diet and physical exercise are actually good predictors of mortality compared to other risk factors for premature death, such as the five highest-ranked risk factors worldwide: Hypertension, tobacco use, high blood glucose, physical inactivity, and overweight/obesity contribute to 13%, 9%, 6%, 6%, and 5% of global deaths, respectively [65,66,74-78]. Based on science-based recommendations, the world´s leading nutritional, sports and health organizations have released guidelines which emphasize the importance of permanently balancing diet with sport and exercise in order to achieve better individual health [2] (pp. 418-419).

Therefore, in order to achieve better health for athletes, the foundation of health should be based on a minimum of two strategies which are ideally interwoven and implemented on a regular basis in every day schedules, with the two main elements being (1) A healthy diet permanently linked to (2) Regular sport and exercise. A healthy diet – at best whole food vegan diets – intrinsically linked to regular sport and exercise – at best moderate intensity on a daily basis – may offer the most promising key intervention for both an athlete`s sustainably optimum health and the resultant physical performance [2] (p. 391), and thus should be transferred and integrated into the athlete's daily schedule.

As both these crucial elements of health occur naturally multiple times in a day, a healthy vegan diet can be easily and practically applied to sports and various settings, if desired.

Vegan Diet - Foundation for an Athlete's Health and Sporting Success

There is a consensus that diet, in addition to but more important than sport and exercise, is the basic foundation for health, and thus is highly relevant to an athlete`s state of health. Therefore, rather than focusing on single foods or nutrients to address health problems, holistic dietary schemes and comprehensive lifestyles should be addressed [55-57,79-82], [55] (pp. 36-37, 62-65, 133-138), [83] (p. 38), [84] (pp. 36-37).

Nutrition should supply the body with all vital nutrients, preserve performance capacity (physical and mental), reduce the risk of chronic diseases, and promote health [85] (pp. 49-50). However, modern nutritional behaviors are known to cause dietary-induced chronic diseases and premature death [2] (pp. 387-388). A growing body of evidence-based data underlines the fact that diet, along with other lifestyle factors such as sport and exercise, plays a key role in the development of certain diseases [2] (p. 413).

Based on scientific evidence, there is a growing interest in and appreciation of vegetarianism [83,86], but especially of veganism [27,85,87], [85] (pp. 49-50, 123). Over and above energy intake, it is due to the characteristics of plant foods that there is a wide range of diet-related health benefits from adopting vegetarian but in particular vegan diets [26,87,88]. Table 2 presents an overview of the health benefits resulting from vegan (vegetarian) diets (without claiming to be complete).

Adequacy of vegan diets - benefits to human health

The first study ever performed on vegans which investigated their state of health, morbidity and mortality linked to chronic diseases was published in 1978 and showed distinct advantages of vegan diets over non-vegan diets [89]. Two years later, in 1980, the Academy of Nutrition and Dietetics (AND, formerly American Dietetic Association: ADA) published its first position statement on vegetarian diets. Since then, cumulative evidence has repeatedly confirmed that vegetarians on average are healthier than non-vegetarians.

Numerous reputable studies (e.g. Adventist Health Studies 1 and 2, GEICO Study) support the clear benefits of vegan diets compared to non-vegan diets [90-93]. Based on the scientific literature available, the Physicians Committee for Responsible Medicine found that health benefits increase as the amount of food from animal sources decreases, and concluded that the vegan diet is the healthiest diet overall, even healthier than vegetarian diets [94]. The health status of vegans is more often within the normal range (eg. blood pressure, cholesterol levels, and BW) [83] (p. 92), [85] (pp. 105-106). The BW and Body Mass Index (BMI) of vegans are lower (adherence of ≥ 5 years) than vegetarians and omnivores [26,87,90,95-99], and vegans suffer much less frequently from being overweight and obese, and from several other diseases [26,88,99]. Moreover, vegans are more health-conscious (active on a regular basis, no or less consumption of alcohol or tobacco) [85] (pp. 105-106). Together, these aspects create the optimal basis for improving an athlete`s performance.

The AND has declared in their current position statement [88] that well-planned vegetarian and vegan diets are (1) Healthy, (2) Nutritionally adequate, match dietary guidelines and meet current recommended intakes, (3) Provide health benefits for the prevention and treatment of certain diseases, and (4) Are appropriate for people at all ages as well as athletes. Seven of the largest specialist associations for nutrition worldwide agree with the latest AND positions [100-107]. However, there is a consensus that vegans have to take special care to ensure a sufficient supply of vitamin B12 by reliable sources, such as fortified foods or supplements [26,88], [27] (pp. 48,102), [85] (p. 121).

Regarding the prevention of diseases, the AND [26] position not only confirms, but also underlines and explicitly highlights their former statement [85], that "there are tremendous advantages toward prevention of chronic health conditions by adhering to a vegetarian eating pattern". The evidence-based literature proves that vegan diets positively influence the development, prevention, and therapy of chronic, inflammatory, and degenerative diseases. Regarding preventive and therapeutic diets, the vegan diet is highlighted as being the most beneficial diet [26,88] known to serve as an effective therapeutic tool in relation to hypertension [87,108-111], diabetes mellitus type 2 [26,108,112-116], atherosclerosis [26,31,88,95,117-119], and Cardiovascular Disease (CVD) [93,108-111,115,118-127], amongst others [84] (p. 92), [85] (p. 123). Moreover, with special relevance to athletes, the vegan diet in particular beneficially affects both BW control (overweight, obesity) [26,90,93,95-99,108,115,127-129], microinflammation [17,130], and chronic systemic inflammation [99].

Overall, the health benefits of vegan diets are sound, in addition to the good health of vegetarians and vegans being sound, too [90,131-133]. Thus, veganism can be conclusively recommended [26,27,134], (pp. 105-106, 196-198), [85] (p. 123), even for athletes, as the basis for maximum health, which itself is a prerequisite to sporting performance and success, ranging from daily participation to winning medals Table 2.

Table 2: Overview of the health benefits resulting from vegan diets.

No.	Health benefits (abbreviated) & important results (in extracts, abbreviated)	References
1	↑ Higher life expectancy and lifespan: Eating vegetarian for > 17 years has been connected to + 3.6 years, particularly vegans have been reported to have the highest life expectancy ↓ Reduced mortality risk and lower risk of most main causes of mortality ↓ Lower all-cause mortality (up to - 20%, maximum with fresh fruit - 21%) ↓ Lower mortality from CVD	[89, 90, 92, 96, 133, 149, 164, 288-307], [83] (pp. 92, 189)
2	↓ Resting heart rate (associated with longevity, distinct gain in lifespan) in order to protect, maintain and improve heart health and cardiovascular health	[179, 181, 182]
3	✓ Plant protein is adequate to meet protein requirements at all ages (balanced vegan diet, when energy intake is adequate) ✓ Total and daily protein intake is adequate (intake: 10-12% in vegans) ✓ Current protein recommendations and also protein needs are met or exceeded without the use of additional protein supplements	[9, 19, 20, 22, 26, 88, 170, 174-176], [163] (pp. 15, 67, 77-79)
4	↑ Better up to highest rated diet compared to mixed diets considering quality of diet contribution to healthy eating (Alternative Healthy Eating Index, Healthy Eating Index 2010 and the Mediterranean Diet Score) ✓/↑ Good/high quality of plant protein (grains, legumes, pulses, beans) ✓ Plant protein provides all amino acids ✓ Plant protein beneficial to (sustainable) health ↑ Plant protein healthier than animal protein: Supplies almost no saturated fatty acids, no trans-fatty acids, no dietary cholesterol, good source of complex carbohydrates, fiber, iron, zinc, resistant starch, antioxidants, phytochemicals ↓ Plant protein associated with ✓/↑ Good health of gastro-intestinal tract and heart ✓/↑ Good bone health (mineral density, no higher risk for osteoporosis and fractures) ✓/↑ Good muscle health (preserving muscle mass and strength, metabolic health, functional capacity) ↓ Lower blood pressure ↓ Reduced blood lipid and LDL levels ↑ Improved insulin sensitivity ↑ Improved menopausal symptoms and female osteoporosis ↓ Reduced risk, lower incidences of certain cancers, and prevention (reversal) of cancer ↓ Lower mortality risk and lower mortality from (1) CVD (- 12%) and (2) all-cause (- 10%), a calculated reduction of up to - 10% in global deaths with 8.1 million lives could be saved per year	[26, 31, 88, 146, 149, 162, 172, 175, 177, 178, 188, 243, 249, 308-318], [2] (pp. 388-389, 402, 410-413, 416), [27] (p. 43), [163] (pp. 65, 74, 77-79)
5	↓ Fewer biological hazards, toxic substances and noxious residues of chemicals (agricultures, life stock farming)	[155, 156, 165], [154] (p. 103)
6	↑ Naturally provides high nutrient density, and high amounts of complex carbohydrates ✓ Meets nutrient recommendations ↓ Less calorie-dense, lower total calorie intake, less saturated fat, cholesterol intake (than non-vegan diets) ✓/↑ Naturally provides the highest alkalizing potential (low-PRAL: specific fruits/vegetables down to - 23 mEq/day; vegan meal down to - 22.9 mEq/dish; vegan diet down to - 39 mEq/day)	[26, 88, 138-142, 144-146, 188, 203-206]
7	✓ Species-appropriate diet ✓ Adequate diet for all ages (pregnancy to elderly), and for athletes ✓ Recommended as diet for permanent adherence (wholesome, natural, vegan diet), counted among alternative diets, with vegetables, fruits, whole grains (products), potatoes, legumes, nuts and herbs as central food groups	[26, 88, 187], [2, 55], (pp. 36-37, 62-65, 133-138), [83] (p. 38)

8	✓/↑ Inexpensive and safe intervention (dual, integrated guidelines: Vegan diet permanently linked to daily moderate sports and exercise)	[319-321], [2] (pp. 418-419)
9	✓ Good state of health is sound ✓ Health status more often within normal range ↓ Lower BW and lower BMI (vegans are leaner) ↑ Better BW control/management ↓ Lower blood pressure ↓ Lower blood levels of total and LDL cholesterol (with lower risk of CVD) ↑ Healthier than non-vegans ↓ Suffer markedly less frequently from illnesses, infections and chronic diseases ↑ Increased antioxidant status (to prevent LDL oxidation; to reduce exercise induced oxidative stress; plant polyphenols protective to cardiovascular system) ↑ Improved (significantly lower) biomarkers of inflammation and immune defense (serum CRP, fibrinogen, interleukin-6; total leukocyte levels; lymphocyte responsiveness; natural killer cell functionality) ↓ Less micro inflammation and reduced chronic systemic inflammation ↓ Associated with fewer allergies than with vegetarian diets ↓ Lower morbidity	[12, 18, 26, 31, 87-90, 92, 93, 95, 97-99, 108, 122, 123, 128-133, 137, 164, 262, 263, 266, 287, 291, 299, 306, 322-324], [83] (p. 92)

Animal protein – detrimental to overall state of health: A typical 'Western diet', also described as a balanced mixed diet (generally defined as the reference diet), is characterized by high intakes of calories, total, trans and saturated fats, cholesterol, meat (especially red and processed meats) and animal products, salt, sugar and refined carbohydrates, together high in 'empty' calories, but with low intakes of vegetables and fruits, dietary fiber, micronutrients, and phytonutrients (eg. polyphenols, omega 3 polyunsaturated fatty acids) [135-137]. The Western diet is a known risk factor for metabolism-induced inflammation associated with obesity [137].

It is further characterized by a high dietary acid load [138-145] that ranges of 50-70 mEq/day. Generally, a specific kind of diet can markedly affect the metabolic regulation of the organism with its characterizing food items, micronutrient profile, and capacity of acid or base production providing acid or alkaline precursors influences systemic blood acid-base status (pH-value) and acid-base balance (eg. quantified by PRAL (mEq/100 g) - the potential renal acid load) [144,146]. It is well known that foods and dietary patterns rich in protein (high-PRAL food items like eg. meat, cheese, eggs) increase the acid production and lead to high acid load and systemic acidosis, while most plant foods have a low potential to produce acids (low-PRAL food items)

[138,139,141,144], even from plant-based dietary supplements [140].

However, diet-induced low-grade metabolic acidosis is buffered mainly by increased bone resorption, and is associated with the development of metabolic alterations and complications (eg. bone disorders negatively correlated with bone mineral density, but positively with fracture risk, insulin resistance, diabetes, hypertension, chronic kidney disease, low muscle mass, renal lithiasis, non-alcoholic fatty liver), and is associated with the development of chronic diseases [144,146].

It is accepted that foods from animal sources are mostly highly processed products [120,147], which, in addition to protein, contain other components such as sodium, nitrates and nitrites that are suggested to negatively affect health [148-153].

It is well-known that products from animal sources, such as meat and processed meat, chicken, fish, shellfish and seafood, milk and dairy products, and eggs, have been repeatedly detected to have markedly higher contamination by toxic substances than products derived from plant foods. These substances include residues from pharmaceutical drugs (e.g. hormones to increase growth, fertility and lactation, ataractics, tranquilizers and antibiotics), industrial toxins (e.g. dioxins) and heavy metals (e.g. lead or mercury) [2] (p. 400), and higher levels of pesticides (eg. 14-fold for meat, 5-fold milk) [154]. Up to 92% of human exposure to dioxins, furans and Polychlorinated Biphenyl (PCB) comes from the consumption of animal foods (meat, fish and shellfish, and dairy products), compared to about 8% resulting from eating plant foods [155,156]. The exposure to hazardous residues is detrimental to human health [26,147], [2] (p. 400), and is particularly detrimental to an athlete`s state of health.

Evidence-based data has also shown frequent meat (including fish and seafood) consumption to be the major risk factor for chronic disease [27] (pp. 105-107). Disadvantages of red and processed meat consumption mostly result from the excessive intake of saturated fats [157,158], along with other substances contained in animal products, and result in an intensified risk of hypertension [159], CVD and strokes [148], diabetes mellitus [160], cancer [161], venous thromboembolism [157], impaired bone health and osteoporosis, and renal disease [162,163] (pp. 43, 66). Moreover, the association of high intakes of animal protein with a reduced lifespan [83] (p. 189), [149], by causing a higher risk of premature mortality from (1) all-causes (+ 2 – 34%), (2) CVD (+ 8 – 29%), and (3) cancer is generally accepted. Furthermore, a recent study has found that even with a high intake of fruit and vegetables (food groups known to be protective to health), the negative effects of red meat consumption on mortality (higher risk of all-causes (+ 21%) and CVD (+ 29%)) were persistent and could not be counteracted or compensated for [164].

Overall, the conventional dietary pattern is known to cause severe health problems [136]. Therefore, despite the claimed benefits of diets based on meat and other animal protein, challenges to human health remain [165].

In the light of evidence based on large-scale prospective cohorts, epidemiological studies [2] (pp. 412-413), and the aforementioned background numbers from current surveys, these factors which are suggested to negatively affect health would be relevant to about 86 – 94% of the public and of particular interest for athletes.

Plant protein – low-grade quality or beneficial to heart health and muscle: Even today, meat remains prestigious and a symbol of masculinity – especially among men and athletes [2] (pp. 392, 396, 397), [166]. The conventional male archetype or even male role concepts are associated with physical performance (capacity), strength, potency, domination, and power [166-168]. The renunciation of meat and animal products could lead to male vegans in particular not being considered socially as 'real' men, especially in the perception of the athlete`s peer group. Not to fulfill this stereotype could lead to social isolation and exclusion, which in turn could result in a reduction in self-esteem [169]. This issue might be especially relevant in sports and relates directly to the acceptance of (male) vegan athletes. Therefore, protein constitutes a much debated issue in both the public and sports [163] (p.66), [170].

Although the health benefits of vegan diets are sound, the prevailing opinion that plant protein is low-grade is a still widespread belief. This is why vegans are repeatedly asked with subliminal prejudices, namely: ´Plant protein is of inferior quality, isn`t it?´, and ´Where do you get your protein from?´.

Protein is a key for building and maintaining the body's tissues, and necessary for promoting the repair and renewal of damaged tissue, including muscle. Except for fruits, many plant foods are high in protein, such as soybeans and lupins, peanuts, potatoes and rice, which contribute about 40%, 25%, 8% and 8% of total energy, respectively. On a caloric basis, many plant foods are in fact higher in protein content than animal foods (high fat content) [163,171], which aid BW management. Plant sources of protein, such as nuts and legumes, also provide numerous other nutrients beneficial to health, such as carbohydrates (up to 50%, low glycemic index), dietary fiber (up to 37%), vitamins, minerals and phytochemicals [83,162].

According to the AND [26], vegetarian and vegan diets provide the same protein quality as meat-based diets. Research suggests that, although vegan diets may be limited in leucine, lysine, threonine, tryptophan, or methionine [31,172], the quality of plant protein such as of grains and legumes is good, but the protein quality of soy in particular is comparable to animal protein [26], [163] (pp. 74, 77, 79).

Based on a well-balanced vegan diet with adequate total calorie intake, which includes a big variety of plant foods and supplies sufficient amounts of all essential amino acids [26,31,88,171,173-175], [163] (pp. 65,78-79), vegans of all ages typically can not only be adequately supplied with enough protein to meet their recommended daily intakes, but can even exceed their protein requirements [9,26,88,175], [163] (pp. 15,67,78), without the use of additional protein supplements [176]. According to ample scientific evidence, both the amino acid and protein needs of non-active vegans, and even the higher requirements of athletes, are easily met with a vegan diet [26,88,173,175,177], [163] (pp. 65, 78-79). Moreover, the AND [26] and ADA [31] together with experts on protein nutrition agree that - when an assortment of plant foods is eaten over the course of a day – there is no need for nutritional behavior like intentional 'protein combining' or 'complementing' when composing and preparing meals in order to obtain all the essential amino acids, not even for vegan athletes [26,31,177].

The Framingham Third Generation Study has recently found that dietary protein is associated with musculoskeletal health, independent of dietary pattern [178]. Therefore, a vegan diet can equally contribute to muscle health just like any other dietary pattern.

Moreover, it is generally accepted that heart health and resting heart rate, and thus cardiovascular health, are highly affected by both diet and sport and exercise. However, the evidence-based literature shows diet to be the most powerful lifestyle factor in relation to health protection and a healthy heart, even more than physical exercise [179], [2] (pp. 390-391).

In a 16-year follow-up study, an increased resting heart rate has been found to result in premature death more frequently [180]. In addition, an increased risk of premature death (+ 10 – 20%) has been found to result from every 10 bpm increase in heart rate, with a resting heart rate of > 65 bpm having a strong independent effect on premature mortality [179]. Therefore, a drop in resting heart rate from 70 to 60 bpm, following cardiac slowing (myocardial metabolic rate associated with reduced resting heart rate) over a lifetime is suggested to increase lifespan by 13 years [181].

In general, athletes have lower resting heart rates (≤ 60 bpm) than non-active people, with lower resting heart rates correlating to higher fitness levels [180]. In theory, without physical exercise one could increase lifespan by about one decade or more (maximum lifespan by 1 beat/second) [179] by reducing the resting heart rate to the same level as athletes', just through eating legumes and pulses amongst other plants. The daily intake of one cup of beans, chickpeas or lentils over 90 days has been shown to reduce the resting heart rate (-3.4 bpm) by the same amount as exercising for 250 hours on a treadmill [182]. With regards to a healthy heart being an essential prerequisite for an athlete' s peak performance, a current meta-analysis has found that a vegan diet is associated with a more favorable cardiometabolic profile, in contrast to that of a mixed diet [27,85,87].

Overall, the claim that vegan diets are inadequate to promote health due to "poor-quality plant protein" and "insufficient amounts of protein" can no longer be upheld [2] (p. 399). Thus, the concern that especially vegan athletes might not consume adequate quality and amounts of protein is unsubstantiated [26,88,173,175,183,184]. Overall, vegan diets constitute an optimal basis for participation in sports.

Benefit-Risk-Ratio of vegan diets as a tool for athletes

A good or even maximum state of health is not only relevant to but also a crucial condition for sporting performance and athletic success. Therefore, from an athlete´s perspective, rating the benefits and potential risks that might emerge from a vegan diet can be helpful when deciding whether to put it into practice in sports (school, training, and racing) or not.

Current scientific evidence has resulted in a transformed rating of vegetarian and vegan diets, initially from a prejudiced perspective [185], then to questioning their adequacy, then to being equal to conventional diets [85] (pp. 49-50). Growing scientific interest is now focusing on associations with promoting optimal health [163] (p. 5), and their impact on sports performance. Today, the positive and negative effects of vegetarian kinds of diet on health are well-known. The cumulative findings show that well-planned vegan diets are more health-promoting and less harmful to health than conventional diets, with the health benefits of vegan diets clearly exceeding the potential risk. However, the ever-growing body of scientific data provides a significantly broader basis in favor of vegan diets, showing that the beneficial effects of vegan diets by far outweigh potential detrimental effects [86,133,134,186], [85] (pp. 49-50). Since diets like the wholesome plant-based diet, including vegan kinds of diet, have been extensively studied, they have been convincingly proven to be suitable as permanent diets, and are recommended for continuous adherence [187].

Nowadays, when protein deficiency occurs, it almost always results from inadequate energy intake (in poor regions such as developing countries) and not from the consumption of protein of inferior quality [163] (p. 65). Most people in industrialized regions (eg. Europe, USA) are oversupplied with (animal) protein and thus get sufficient protein and even levels exceeding the Recommended Dietary Allowance (RDA) level of total protein intake [67] (pp. 4, 82, 96), [163] (p. 67).

Considering the so-called potentially critical nutrients (vitamin B12, vitamin D, iron, iodine, calcium, zinc, long-chain omega-3-fatty acids), vegan diets in particular have been formerly described as deficient [83] (pp.

Table 3: Overview of macronutrient distribution (A) following current guidelines considering meal composition of conventional mixed diets (as percentage of total energy intake (%)); and (B) macronutrient distribution from individual surveys (2000-2009) for omnivores, vegetarians and vegans, and from a meta-analysis of observational studies (1984-2017) of vegans versus omnivores (as percentage of total energy intake (%) and as mean value including range (min-max)).

	Carbohydrates (%)	Protein (%)	Fat (%)
Current guidelines (A)[1]			
EFSA	45-60	12-20	20-35
IOM	40-65	10-35	20-35
Intakes from individual surveys (B)[2]			
Vegan	50-65 (53.8-69.1)	10-12 (8.2-13.5)	25-30 (18.4-33.2)
Vegetarian	50-55 (51.0-68.0)	12-14 (8.4-15.3)	28-34 (20.0-36.9)
Omnivore	≤ 51 (44.0-64.9)	14-18 (8.8-17.9)	34 (23.4-37.1)

[1][175,212-214]; [2][87], [163] (pp. 14-15, 464-468)

229-234). However, some of these nutrients (calcium, iodine, iron, vitamin D, zinc) are not only key for vegans, but critical for omnivores and vegetarians, too. Also, long-chain omega-3-fatty acids as well as vitamin B12 have been shown to be not exclusively critical to vegans. Long-term supply of vitamin B12 can safely be provided by fortified foods and products (ie. plant milk, tooth paste) and even supplements [85] (p. 121). In this context, it is noteworthy to mention that vitamin B12 deficiency is common and not infrequently detected in older omnivores (reduced absorption, drug ingestion such as inhibitors to gastric acid). Since it is generally believed, also amongst physicians, that vitamin B12 deficiency does not exist in meat-eaters, vitamin B12 blood levels are usually not checked, to the patients´ disadvantage. As a consequence, it then often goes undetected [85] (p. 121).

Due to the low intakes of protein and calcium (see Table 3) vegetarian and vegan diets are expected to cause low bone mineral density and osteoporosis. Depite this, the bone health of vegetarians and vegans is good. The very low or absent dietary acid load resuting from vegetarian and vegan diets - linked to a high intake of potassium from potassium-rich foods such as fruits and vegetables - reduces bone resorption and promotes bone formation (higher density), and might be an important factor for the protection of vegetarians from osteoporosis. Bone mineral density is not decreased in vegetarians and in most vegans [146,188], and concerns regardering an increased risk of osteoporosis, and thus fracture, is unsubstantiated, except for vegans who consume particularly little calcium [146].

Generally, nutrient deficiencies (eg. iron, iodine, vitamin D, vitamin B12) occur in all dietary patterns, including mixed diets [26,189], [2] (p. 411). Thus, vegan diets are nutritionally not more deficient than any other kind of diet [190]. In terms of daily intake, in line with a brief review that found seven nutrients (calcium, fiber, folic acid, iodine, magnesium, vitamins C and E) were deficient with a mixed diet [191], a recent study found that omnivores on average do not meet the recommended daily intake of six nutrients (calcium, copper, folate, iron, magnesium, vitamin E) [192]. In vegetarians and vegans, however, the daily intake was insufficient in three nutrients (calcium, zinc, vitamin B12) [192], with vegans being deficient in iodine instead of zinc [191]. Furthermore, it is known that vegans on average are better supplied with some nutrients, such as beta-carotene, vitamins C and K, folic acid, magnesium, potassium, fiber and phytochemicals. For other nutrients, such as vitamin E, thiamin, biotin and pantothenic acid, supply is equal to other kinds of diet [85] (p. 121).

Numerous studies have recently demonstrated that in most, if not all cases, the observed deficiencies usually emerge from poor application, i.e. by misapplied dietary behavior [86,133,134]. The nutritional adequacy of any particular kind of diet, including the vegan diet, depends on personal nutritional knowledge, how to appropriately compose and prepare, and also how to diligently supplement one's diet [86,92,133,193,194]. Some studies have found that vegans either do not know how to compose and prepare a whole food vegan diet, or do not apply this knowledge. In these specific cases, significant risks exist resulting from personal misbehavior, but these cannot be extended to the vegan diet per se [26,85] (p. 120).

It is generally accepted that with a well-composed wholesome vegan diet appropriately supplemented by vitamin B12 there are no risks for any age or any professional group [85] (p. 121), including athletes. Therefore, since potential deficiencies can be easily avoided [26], a vegan diet lacking any deficiency can result from careful planning, appropriate composition and preparation, and with adequate supplementation, when energy needs are met [26,31,88]. However, with the threat of dangerous half-knowledge is also persistent and often widespread, there is an obvious contradiction, because scientifically proven reality is turned upside down when discussions lack evidence and thus rate vegan diets as eg. unhealthy, which seems inappropriate considering the substantial evidence-based data available [85] (pp. 122-123).

Recent results from the Global Burden of Disease Study [195] showed dietary risks account for 22% of all deaths among adults globally, with > 50% of diet-related deaths caused by poor dietary habits mainly characterized by insufficiency due to low intakes of fruits and whole grains (but high of sodium). A nutrient-dense vegan diet rich in wholesome foods including grains, legumes, nuts, fruits and vegetables is a sound, evidence-based recommendation, and thus should be advised as a healthy option [26]. Adopting a wholesome vegan diet high in nutrient-rich, fresh, organic foods, preferably combined with unprocessed foods, that is carefully planned and diligently implemented in an athlete's everyday schedule, creates advantageous conditions for maximum health and performing at one´s best [147], [2] (p. 401).

Advantages to Sports Emerging from Vegan Diets - Prerequisites for Successful Athletes

The healthy human is only the prerequisite for the successful athlete. Achieving the cumulative health benefits that emerge from the permanent and inter-related application of both the key lifestyle factors - a (wholesome) vegan diet and (daily, moderate) sport and exercise – might be relevant to the active people and recreational athletes in general, but are even more important in ambitious, professional and top level sports. Generally, a conscious change in an athletes' perspective on health has the potential to initiate an advantageous paradigm shift in the behavior considering sports nutrition and performance.

According to the ADA [174], "athletic performance and recovery from exercise are enhanced by optimal nutrition", and thus "recommend appropriate selection of food and fluids, timing of intake, and supplement choices for optimal health and exercise performance." The American College of Sports Medicine (ACSM) [174] highlights in their current joint position statement, that "the performance of, and recovery from, sporting activities are enhanced by well-chosen nutrition strategies". Therefore, they provide nutrition guidelines to support optimal health and athletic performance, spanning from training to racing.

Even after decades of research focussing on the effects of vegetarian diets on health, knowledge is sparse about if and how veganism affects athletic performance. Despite the abundance of evidence on the health benefits that emerge from particularly vegan diets [88], whether a vegan diet per se promotes athletic (peak) performance or not is still unclear and remains to be determined [11,12,101,196].

There is ample evidence from laboratory and field studies demonstrating that a well-planned vegetarian and vegan diet can meet the energy and nutritional needs of competitive athletes [95]. Since well-planned vegan diets are healthy and nutritionally adequate, even for athletes, the ACSM [173] emphasizes that vegan diets can even meet the increased nutritional needs of competitive athletes when energy requirements are met, and when they contain high levels of vegetables and fruits, nuts, whole grains, soy products, dietary fiber, antioxidants and phytochemicals [26,31,101,102,105].

A vegetarian or vegan diet was first recommended in 1982 as the ideal dietary strategy for athletes but most effective for endurance athletes (eg. runners, cyclists, triathletes) [48], even though information about (strict) vegetarian diets linked to athletic performance had been sparse, if it existed at all. 32 years after the initial recommendation, Austrian researchers documented for the first time the successful implementation of vegan in-race dietary tactics in ultra-endurance sports [20]. After eight consecutive stages of the Mountain Bike Transalp Challenge 2004, which was shown to be physiologically very demanding [197], the final performance on a high-carbohydrate vegan diet was +20% better than expected. Moreover, the vegan athlete was able to maintain an average speed of 15.6 km/h resulting from an exercise intensity of 88% of race induced maximum heart rate (80% of laboratory determined maximum) over the full stage race, with respectively 95% and 83% of in-race and total energy coming from carbohydrates [20].

Since there is no proof to suggest that a vegan diet per se can improve human performance [11,12,101,196], research about the effects of long-term or even lifetime adherence to veganism in athletic performance is still limited to only two case studies performed on vegan ultra-endurance athletes. Together, these data show that vegan athletes are not only competitive (physiological profile, race results), but further match the exercise-induced nutritional demands of prolonged high intensity training and racing [20,198]. These results suggest that a carefully planned vegan diet diligently put into practice can be effective for other athletes and specific athletic populations, too.

In addition, current findings from the NURMI Study (Step 2) showed 91 vegan runners (of total 245) to be more health-conscious than non-vegan runners [24]. Overall, within eight dimensions of health status in endurance runners, the vegan dietary subgroup contribution to runners' good state of health ranged from 61% – 91%. With 75% (± 20%, $p = 0.001$), showing the highest scores within the *food choice* dimension, they reported choosing food more often because it is good for maintaining health (95%, $p = 0.05$), choosing it more often to obtain specific ingredients, eg. phytochemicals (59%, $p = 0.007$), and even to avoid specific nutrients such as sweeteners (80%, $p = 0.046$), saturated fats (72%, p

= 0.007) and cholesterol (65%, p < 0.001). Conclusively, vegan endurance runners were found to contribute most beneficially to their overall state of health, mainly because they reported to be extraordinarily health-conscious, in particular due to their food choice behavior. In line with a recent study performed on ambitious recreational runners in the laboratory [196,199,200], these findings support the notion that adhering to a vegan dietary pattern is compatible with ambitious endurance running [24]. Further results from Step 2 showed vegetarian and vegan endurance runners had a high quality of life, like the omnivorous runners, too [21].

However, athletes may reach the point in their careers when it becomes necessary to search for alternatives and possibilities to further develop or completely tap their athletic potential. Some take pills and/or powders while others switch to a vegetarian or vegan diet in order to gain advantages in both training and racing, benefitting post-exercise recovery and regeneration, and to enhance total performance capacity [201].

From the authors´ experience, not only among the normal population but also frequently with athletes and their coaches, nutritional knowledge is often alarmingly poor. In their quest to be extraordinarily well fueled, along with their belief in consuming high quality foods and nutrients to gain superior health, athletes often inflict harm on themselves through detrimental nutrition and suspect fueling practices, rather than nourishment for better fitness and peak performance [2] (p. 436).

Characteristics of whole food vegan diets that aid athletic performance

Based on the characteristics of plant foods, the nature of the vegan diet is especially unique compared to non-vegan diets. The nutrient-dense, high-carbohydrate, high-fiber, but low-fat (inclusive saturated fatty acids) and thus low-calorie, and zero cholesterol nature of vegan diets is especially characteristic. In general, a complete wholesome vegan diet is rich in nutrients due to high intakes of vegetables and fruits, legumes, soy products, whole grains, nuts and seeds (respectively rich in fiber, phytochemicals and vitamins). The high ingestion of fiber due to the high intakes of plant foods results in rapid satiety and thus decreased total energy intake, which aids in the reduction of BW by reducing of body fat mass [13,16]. Therefore, several indexes that have evaluated overall nutrition relating to healthy eating have rated vegan (vegetarian) diets as typically better (highest scores) than mixed diets (lowest scores) [26,88,202], (p. 79).

The key benefits to vegan athletes compared to non-vegan foods and products are the higher intakes of complex carbohydrates, dietary fiber (only present in plants), antioxidant vitamins C and E, folic acid, magnesium, potassium and sodium, carotenoids and other phytochemicals [26, 86, 88, 147, 177], [83] (p. 190).

In general, specific food items markedly affect the metabolic regulation of the organism by changes in the acid-base balance with vegetables, fruits and potatoes (low-PRAL food items) having the highest alkalizing potential [138,139,141,144,146]. While average values of calculated dietary acid load for specific fruits and vegetables are down to -23 mEq/day [203], milk and yogurt are of about +1 mEq, and meat, fish, poultry, egg and even some grain products of ≥ +7 mEq [204], with cheese alone ranging from +26 -34 mEq/day [145]. The pronounced alkalizing (low-PRAL) character of vegan diets increases bases by high intakes of fruits and vegetables that generally pose the lowest acid load [205] and reduce acid excretion [141,144,146,188,204]. Consequently, comparing the alkaline load of a typical vegan meal (-22.9 mEq) or even vegetarian meal (-10.9 mEq) to the acid load of an omnivorous meal (+41.7 mEq), the metabolic burden is calculated to markedly differ (64.6 mEq) [142,145]. Thus, not suprisingly, a markedly different metabolic burden was found for vegan (-15.2 mEq/day up to -39 mEq/day), vegetarian (-1.5 mEq/day), and omnivorous diets (+19.6 mEq/day) [188,206]. This is in line with the mean net acid excretion values found to significantly differ for vegans (17.3 mEq/day), vegetarians (31.3 mEq/day), and omnivores (42.6 mEq/day) [207].

However, because diet and exercise alone may affect acid-base balance, and thus pH-value [208], their combined impact is relevant to both anaerobic and aerobic exercise performance. During sports, the exercise-induced physical stress challenges an athlete's metabolism through complex demands (eg. gas-exchange capacities, buffering enhanced accumulation of blood lactate and hydrogen ion levels reducing the pH-value). Resulting from the digestion and the break-down of foods and nutrients from animal sources, the organism has to compensate for harmful substances in addition to catabolic products (e.g. nitrogen, sulfur-containing substances) and low-grade metabolic acidosis resulting from higher dietary acid load [146], which together pose another heavy burden on the exercise-induced metabolism. In addition, the physiological burden on the athlete's organism is markedly less for plant foods than for animal foods. This is due to much lower contamination by health threatening noxious and toxic substances as well as their residues resulting from absorption (ratio of 1:9 from drugs, toxins and heavy metals, along with a ratio up to 1:14 from pesticides) [154-156,165].

The strong alkalizing nature of vegan diets might not only have a positive impact on health [141,144,146,188,204], but also serves as a prerequisite for performance of exercise, especially at high intensities, too. Since non-active vegans show better metabolic parameters than non-vegans [209], vegan athletes will benefit even more from this optimal baseline metabolic status, prior to any single unit of training or racing. As a basis for performance, they lack other negative effects of non-vegan diets (eg. saturated fats, cholesterol, purines, and residues) that would reduce the ability to perform [2] (p. 400). However, compared to a high acid promoting diet, an alkaline promoting diet with a markedly low acid load was shown to increase anaerobic exercise time to exhaustion during high intensity treadmill running by +21%. This was calculated to translate to a 10-times higher reduction in dietary acid load, which is associated with an increase of approximately 5% (6 seconds) [141]. A current study showed an increased diet-induced blood buffer capacity (base excess, bicarbonate concentration), although anaerobic performance was unaffected [210], which may in part be due to the different diets pre-exercise metabolic state [18,211].

Moreover, the positive relationship between intake of specific nutrients (eg. macronutrients such as complex carbohydrates; micronutrients such as zinc; antioxidants like vitamins C and E, polyphenols, beta-carotene) and vegetarian kinds of diet with immune function is evident. Nutritional modulation can play a role in mediating immunological effects with the optimum diet to best support immune defense to prevent chronic inflammation and infections [17,18,137]. Together, low-fat whole food vegetarian diets, but especially vegan diets, beneficially influence inflammation, immune function and antioxidant status by modulating the inflammatory and immune system (elevated biomarkers). Recent evidence indicates such diets to improve (significantly lower) levels of serum C-reactive protein (CRP), fibrinogen, interleukin-6, and total leukocyte concentrations, as well as lymphocyte responsiveness and natural killer cell functionality [17,18]. These advantageous but subtle changes provide positive health outcomes and suggest improvements that translate into benefits for endurance athletes that may result from an optimized intake of phytochemicals (particularly polyphenols) and unrefined carbohydrates, with low intakes of choline, betaine, carnitine and saturated fat at the same time [18].

Together, these facts are fundamentally advantageous to vegan athletes, as they might positively affect exercise performance during training and racing, and likely constitute a good prerequisite for sport and peak performance, too. As vegan diets overall are considered the healthiest kinds of diet [94], vegan athletes are able to achieve optimal effects in order to develop an athlete's overall potential through training and recovery, and then to tap into it fully during races [2] (p. 401).

Macronutrients to fuel for sports

In order to maintain the numerous functions of the human organism, including respiration, circulation, sport and exercise and protein synthesis, energy needed is provided by the macronutrients carbohydrates, proteins and fats [175] (p. 4).

The recommended macronutrient intakes contributing to daily calories reflecting a conventional dietary pattern [176,212-214] are presented in Table 3A. In addition, Table 3B presents the macronutrient distribution for vegans, vegetarians and omnivores, derived from individual surveys, showing that omnivores' intakes contribute considerably more energy from protein and fat, especially when compared to vegans (+11% mean daily energy intake, +27% protein, +25% fat). The daily carbohydrate intake is highest in vegans, and lowest in omnivores (≤ 51%) [87,163] (pp. 14-15) with an evident but inadequate carbohydrate contribution of only 40-45% of total energy intake found in many Western civilizations [215] (p. 181).

Considering dietary recommendations for the non-active general population, a recent study on recreational runners found that carbohydrate intake of omnivores (46.7%) is lower than recommended (> 50%) and significantly differs from the adequate carbohydrate intakes (55.5%) of vegans, along with protein intake of vegans (1.25 g/kg of BW) exceeding recommended levels (0.8 g/kg of BW). It was concluded that vegan recreational athletes gain advantages over omnivores and vegetarians [200].

Carbohydrate is the dominant fuel: Considering their dominance in energy supply, carbohydrates have always been of superior importance amongst all nutrients of the human diet [215] (p.181). However, despite their overriding role, carbohydrates have been, and still are today, usually neglected, while protein is overrated [2] (pp. 397,402). It is evident that carbohydrates are utilized by the body most efficiently and thus constitute not only the preferred fuel at rest. Typically, complex carbohydrates contribute the majority of a vegan's energy intake. Non-active vegans not only match the macronutrient guidelines but also meet the even higher recommendations for athletes as well as their in-race energy needs (Table 3 and Figure 1).

By the early 1980s vegetarian dietary patterns were already being recommended as particularly effective for meeting high energy and carbohydrate demands [48], especially for endurance athletes [47,183]. This is due to the carbohydrate-rich characteristic of plant foods, and since vegetarian diets can help endurance athletes involved in heavy training regimens to achieve their increased carbohydrate needs of up to ≥ 80% of total energy in order to maintain stable body glycogen stores. Carbohydrates supply most of the energy required during sport and exercise which is high in both extent and intensity [216] (p. 412), and can improve race performance [217-221] even at heat [222,223] and exercise intensities > 80% of maximum performance, when large amounts of energy must be provided over long periods (> 90 min) [224-227]. Moreover, pre-exercise or tapering as well as post-exercise and, more importantly, post-race dietary strategies should focus on carbohydrates since they are crucial for optimum performance, recovery and maximizing glycogen resynthesis. Howev-

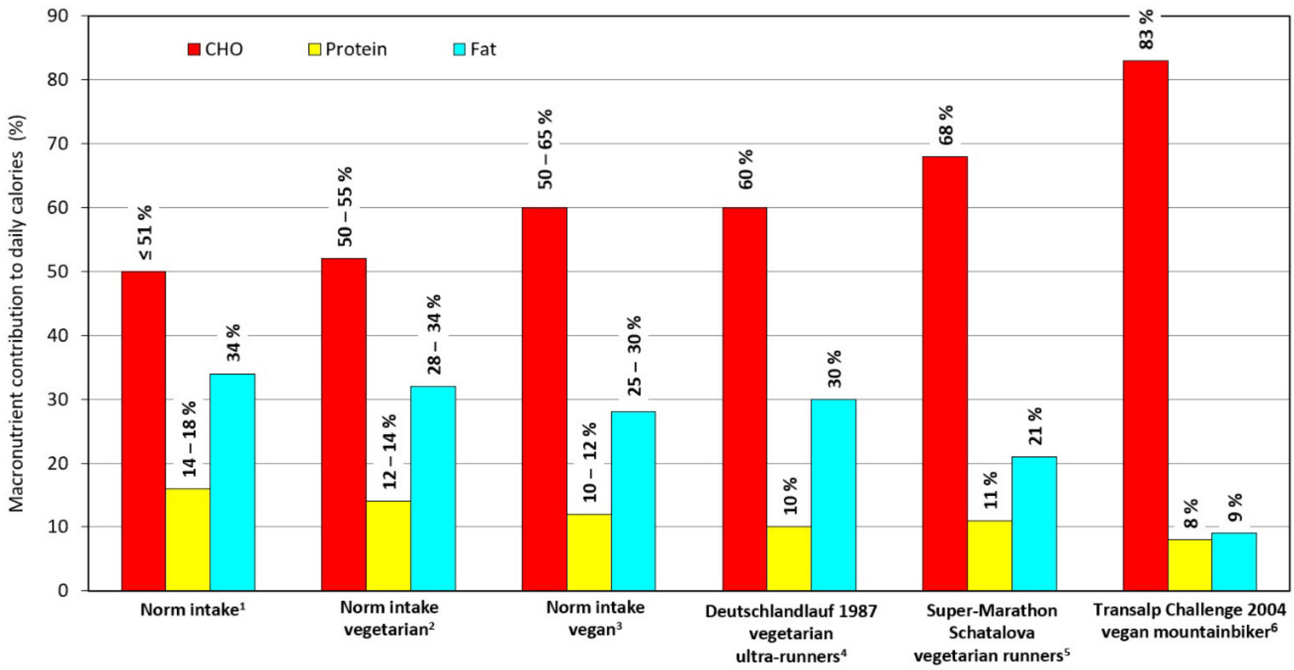

Figure 1: Comparison of macronutrient distribution by intake based on individual surveys of non-active normal populations: (1) Omnivores, (2) Vegetarians, and (3) Vegans, against exercise-induced macronutrient distribution of athletes in ultra-endurance stage-races: (4) Vegetarian ultra-runners during the Deutschlandlauf 1987, (5) Vegetarian supermarathon runners (Schatalova experimental group), and (6) Mountainbike Transalp Challenge 2004. CHO – carbohydrate.

[1,2,3][87], [163] (pp. 14-15); [4][283]; [5][55] (pp. 18-20, 51-52, 60, 64, 160); [6][20].

er, Close, et al. [228] emphasize that not fat or protein but carbohydrate is the dominant fuel for physical performance during both extensive and intensive exercise. In addition to endurance sports, they confirmed the importance of carbohydrates to other types of athletes such as rugby-players [228-230].

Sport and exercise cause changes in macronutrient distributions that are characterized by a more pronounced shift to higher energy provision from carbohydrates (markedly lower from protein and fat). Since exercise-induced energy expenditure is elevated, energy from carbohydrates becomes increasingly important during prolonged high-intensity races (higher challenges to thermoregulatory and metabolic systems), and is even more increased the more intense and the longer the event. As a consequence, a macronutrient ratio of carbohydrates, protein and fat of up to 8:1:1 or, expressed as a percentage of total daily calories, of 80:10:10 occurs. Figure 1 shows this general shift to high proportions of carbohydrates to contribute to total energy.

As is common during intensive racing in heat, the increase in energy expenditure is managed by an even higher need for carbohydrates [19,20], which should be reflected on the plate when planning an athlete´s diet, and when composing and preparing meals [2] (p. 432). Therefore, a minimal carbohydrate to protein ratio [231] of at least 4:1 is advised for meal composition [2] (p. 405). Drawn from the data of individual intakes presented in Table 3B, the carbohydrate to protein ratio of 5:1 in vegans nicely matches this recommendation and provides optimal conditions for promoting an athlete's long-term health and exercise performance, while the omnivores' ratio of 3:1 seems insufficient. Moreover, the ratio of ≥ 8:1 in non-athletes is suggested to benefit health [2] (p. 405), [84] (pp. 25-78), [232] (pp. 83-113), with up to ≥ 8:1 in athletes having been shown to optimally promote race performance in ultra-endurance stage events [20].

To sum up, the quote "carbohydrate remains king" [228-230] succinctly expresses the fact that carbohydrates not only constitute the most important fuel for the nutritional foundation of health, but are also of even more significance to successful athletes, since carbohydrates are key at high metabolic rates and promotes exercise performance. Resulting from this, any athlete should fuel primarily by carbohydrates - even strength athletes [231,232-235] -, with at least 50% of daily energy, or even 60-65% to meet the energy needs considered by sports nutrition recommendations [236]. This is easy to achieve through the high-carbohydrate nature of a vegan diet.

Protein for vegan athletes to build muscle mass and strength: Until today, protein has been overrated in general, and by men and athletes especially, with the majority sticking to the erroneous assumption that 'man requires meat'. Mainly power and strength athletes support and practice the predominant paradigm that the intake of large amounts of protein is paramount for building muscle mass and strength [2,237,238], (pp. 397, 402-403). Protein remains a symbol of bodily potential and vigor, therefore athletes in particular are always concerned about getting enough high-quality protein [163] (p. 65) to build muscle.

In contrast, some recent studies support the fact that the origin of protein is not decisive for building healthy – strength or endurance-compatible – muscles to successfully participate in power or endurance sports [178,239-242]. Across six protein food clusters ('fast food/full-fat dairy', 'fish', 'red meat', 'chicken', 'low-fat milk', and 'legumes' including also nuts/seeds/fruits/vegetables), no differences in muscle mass or muscle strength (m. quadriceps) were observed [178]. Independent of dietary pattern, the daily protein intake (57% from animal sources, 43% from plants) of well-trained athletes active in strength, endurance and team-sport (n=553) was found at > 1.2 g/kg, which matches the exercise-induced recommendations. However, the distribution over the course of the day was found lower than recommended (< 20 g) with 58% of athletes failing to distribute enough protein at breakfast, 36% at lunch and 8% at dinner) and inappropriate to maximize the skeletal muscle adaptive response to training [240]. Independent of the habitual dietary routine of recreational athletes (vegetarians or vegans (n=18) vs. omnivores), creatine supplementation during an 8-week resistance exercise training increased intramuscular IGF-I concentration [239]. In addition, for an increase of 10 g/day of vegetable protein, but not animal protein, a significant increase in distance walked was recently found (+20 m in a 6 min walking test), suggesting plant protein to beneficially affect exercise performance in non-active subjects [241]. Moreover, oat protein was found to be protective considering the negative effects of eccentric exercise, particularly against muscle damage induced by downhill running, as it markedly diminishes muscle soreness, reduces markers for muscle damage (serum creatine kinase, myoglobin) and inflammation (plasma IL-6, CRP levels), and aids in recovery from downhill running in untrained subjects [242].

However, preserving skeletal muscle mass is important to maintain metabolic health and functional capacity [172,243]. Independent of kind of diet, total muscle mass (including circumference of a specific muscle) can be adapted by concrete interventions that are decisive to build muscle mass, eg. the appropriate training stimulus as one crucial factor.

Not meeting the key requirements of adequate (1) Energy intake, (2) Protein/amino acids intake, considering the amount and timing along with sufficient carbohydrate, and (3) High-quality protein (rather than kind of source, eg. soy, rice, wheat, beef, whey, egg) can result in (i) An undesired decrease in BW and muscle strength due to loss of body fat and muscle mass, (ii) A negative effect on health, and (iii) A negative impact on athletic performance [20,170,173,174,231,244], [2] (p. 405), [84] (pp. 55-78), [232] (pp. 83-113). These aspects influence an athlete´s potential to build and maintain muscles that are compatible to high-intensity and/or long-term power and strength sports as well as endurance sports, too.

Although, muscle mass alone as a predictive parameter to performance is not meaningful for rating the appropriateness of specific kinds of diet in sports. To win or lose depends on various performance-determining factors within a specific profile of skills and capacities, and is rather more complex than being limited to muscle mass and/or strength. An athlete's optimal physique is related to factors such as age, sex and genetics [172-174,243], and is linked to the specific demands of a given kind of sports or discipline.

However, among athletes, muscle mass is often believed as the ultimate performance-determining factor, especially in power and strength sports.

A vegan diet supposedly limits the gain of muscle mass and strength, and long-term adherence is even claimed to decrease muscle mass and negatively affect muscle strength. Yet, there is anectodal evidence from world records set by vegan power and strength, and even endurance athletes (as well as their mere participation in Olympic Games and World Championships).

From the experience of mentoring and supervising ambitious (vegan) athletes from endurance to strength sports for two decades, not one of them has reported an undesired loss in muscle mass due to the vegan diet. In addition, with the growing scientific interest especially in vegan diets, there is special concern of the hypertrophic potential of a vegan diet following a resistance training in terms of muscle mass and strength [172,243,245-248], and even from evidence-based literature, this concern is unsubstantiated. Since no study performed on power and strength athletes on long-term vegan diets exists, a decrease in muscle mass and/or muscle strength on a vegan diet still remains to be proven. To date, no single study has shown limitations related to muscle mass and/or strength that result from a (i) Well-planned, diligently conducted (ii) Long-term (iii) Vegan diet (iv) In athletes, since current research is generally lacking regarding the impact on athletic performance from long-term adherence to veganism [170,173,174,244].

There are only two case studies performed on long-term (> 5 years) vegan ultra-endurance athletes, both indicating that muscle mass and strength matches the performance of omnivorous counterparts [20,198] as well as muscle health of non-active people [178]. Therefore, undesired facts that might be due to eg. misinformation, inadequateness or failure in sports-specific dietary or training strategy can result in dramatic disadvantages to an athlete´s health and sports performance, but cannot be attributed to the vegan diet per se.

Yet, the most frequently asked question addressed to vegan athletes is still loaded with severe doubt, and is namely: ´How do you meet your protein needs?´ The International Society of Sports Nutrition (ISSN) [249] concluded in their position paper on protein and exercise that evidence to date lacks proof about whether protein quality from animal or plant origin is superior in terms of optimizing recovery and/or training adaptations.

Because only up to 5% of the sport- and exercise-induced energy needs can be covered by the body's protein stores [11,58], and contrary to common belief, protein is not the predominant fuel. However, during extraordinary metabolic situations such as starvation or extreme BW loss due to dietary interventions, proteins can be catabolized and used as an emergency fuel to supply energy to the body from internal sources, such as from muscle mass or even from the quantity of endogenous protein present in the gut which may be much greater than that ingested [162,163] (p. 76).

The amount of physiological protein required by non-active people is 0.66 g/kg*day of BW, with the RDA of 0.8-0.83 g/kg*day of BW (safety margin for variations such as illness included) [175,214], being markedly higher (+25%) than the needs. A slightly higher figure than this protein intake is recommended (1) Due to the potentially 10% lower protein digestibility of vegetarian diets of up to 1.0 g/kg of BW, and (2) Another approximately 25% increase for those vegans who either might not consume a diet containing a large range of various protein sources but who mainly ingest plant proteins with a very low digestibility, like beans [174,250], [163] (pp. 66-67).

The guidelines for daily protein intake for endurance and strength-trained athletes outline a range of 1.2-1.7 g/kg*day of BW [174], which is supported by protein experts considering an athletes' requirement (1.2-1.8 g/kg*day) [237,251]. Because of the aforementioned lower digestibility of plant proteins, a higher protein intake that equals the respective value of 1.3-1.8 g/kg*day of BW is recommended for vegan athletes [174].

Although not all authorities support higher protein intakes for athletes [174,175], some organizations mention higher figures for protein intake of up to 2.0 g/kg*day (to build and/or maintain muscle mass, to aid metabolic adaptation, repair, remodelling of muscle and whole body protein, protein turnover) [170,173]. Yet, the amount of protein needed to support muscle growth and to maintain muscle mass may be lower for athletes who routinely undergo resistance training due to a higher efficiency of protein use [174,244]. However, since there are no benefits from consuming more protein than recommended [214] (p. 31), [175] (p. 27), and the use of concentrated protein sources such as protein or amino acid supplements of powders and/or pills is unnecessary, even the higher needs (protein, essential amino acids) can generally be met through diet alone [26,58,170].

Although vegan protein intakes of 10-12% are lower compared to non-vegans (Table 3B), they are still adequate to match the even higher protein needs of the heavily-burdened metabolism of athletes. These values, ranging from 8-15% of daily energy, can be easily met and have been described as being adequate to benefit health and athletic performance [19,20,174], [163] (pp. 67, 77-79), [2] (p. 398).

To conclude so far, the lack of evidence does not allow the conclusion of a general rejection, or even to advise against, a vegan diet for building muscles and strength, since it is based on unsubstantiated grounds. Therefore, an athlete can even follow a vegan diet to build muscle mass and strength [178,239-242], [2] (p. 399).

Key nutrients to vegan athletes

As mentioned before, the health of vegan athletes depends on their knowledge of how to plan, compose, supplement and put into practice their athletic diet [92,133,252,253]. Therefore, when energy and protein intakes meet the higher exercise-induced needs [31,88,174], the concern that especially vegan athletes may be at risk of having low intakes of riboflavin, creatine and carnosine [26,31,173,174], as well as of energy, protein, fat, and some key nutrients, has been shown to be unsubstantiated [175,183]. Recently, daily iron intake in vegan recreational runners was found to be adequate as recommended for the non-active general population without supplementation (15 mg), while in omnivore recreational runners it was only sufficient when supplemented [200]. The same laboratory compared the micronutrient status (biomarkers of vitamin B12 and D, folate, iron; serum levels of calcium, magnesium, zinc) of vegan (n = 28) and non-vegan (26 vegetarian and 27 omnivorous) recreational runners [199]. Independent of kind of diet, 8 out of 10 runners of the respective dietary subgroup showed adequate vitamin B12 status with higher levels in supplement users. Mean red blood cell folate exceeded the reference range with highest values in vegans (2354 ± 639 nmol/L) compared to non-vegans (vegetarians: 2236 ± 596 nmol/L; omnivores: 2213 ± 444 nmol/L); and vitamin D levels of vegans (86.2 ± 39.5 nmol/L) were comparable to that of non-vegans (vegetarians: 76.8 ± 33.7 nmol/L; omnivores: 90.6 ± 32.1 nmol/L), with low prevalence (< 20%) of inadequate vitamin D. The authors concluded that the benefits emerging from a vegan diet (carbohydrate, iron, fiber) excel over omnivores and vegetarians for recreational runners, and that a well-planned and supplemented vegan diet can meet the athlete's requirements of vitamin B12, vitamin D and iron [199,200].

Resulting from this, a well-planned and supplemented, and diligently implemented vegan diet is compatible with competitive sport and promotes a good state of health with no risk of developing nutritional deficiencies [10,11,13,26,196,199,200,254], [254] (p.778, 788). However, because non-active vegans have to supplement vitamin B12, it is necessary for vegan athletes, too. Despite there being no need for any other supplementation when vegan diets are based on a big variety of wholesome plant foods [2] (pp. 431-432), supplements might add benefits as part of an athletes' dietary strategy.

However, due to the greatly increased metabolic rate from time to time, well-trained (competitive) athletes generally show a markedly higher need for energy, all nutrients, vitamins and minerals, as well for as other vital substances. As the respective values can vary greatly and depend on many factors such as training and racing, among others, these exercise-induced needs exceed the usual daily requirements and are therefore more difficult to cover by daily meals. Therefore, it is important that all athletes – regardless of which kind of diet – have to be aware of the fact that careful planning and diligent implementation of their personalized exercise-induced diet into daily scenarios is essential for coping with the higher nutritional requirements. This is necessary in order to avoid exercise and diet-related under-supply, which would result in imbalances and/or deficiencies with negative effects on both health and sports performance [10,183,201].

Moreover, potentially exercise-induced and dietary-related imbalances and/or deficiencies should be identified through regular medical check-ups on levels of vitamin, micronutrient and other vital substances by a specialist (sport) nutritional physician. On this basis and only when detected and diagnosed, a sports diet – regardless of whether vegan or non-vegan – has to be balanced and to compensate for any imbalances and/or deficiencies with individualized prescribed supplementation [2] (pp. 432).

In summary, guaranteeing a good state of health is a prerequisite for an athlete's success. Therefore, every athlete is recommended to periodically undergo routine monitoring of vitamin and micronutrient status by individual blood screening, especially to determine the status of nutrients which are key to the athletic metabolism, both regularly during competitive and off-season [22,31], [2] (pp. 431-432).

Advantages to vegan athletes put into practice

After describing all the manifest benefits that emerge from vegan diets, huge potential is still left untouched and available to tap into. This is especially critical for athletes because even today the various benefits that emerge from vegan diets when they are transferred and related to high performance sports are still mostly neglected and not implemented. This means in practice that the facts mentioned above are particularly important to athletes, but finally have to be turned into concrete sports-related action.

Yet, despite this information being available today in an increasingly detailed form, athletes, their families, coaches, trainers, sport scientists and physicians specialized in sports medicine are still unenthusiastic and not only remain skeptical of the potential positive effects that result from vegan diets, but still doubt the beneficial effects of vegan diets on performance. From the experience of 20 years of mentoring and supervising ambitious (vegan) athletes, the author has found that the main reason that people, but especially athletes, still reject a vegan diet is not based on nutritional, physiological, metabolic, health or performance-limiting reasons, but rather the lack of knowledge about evidence-based data and cultural prejudice. In fact, there is no scientific rationale against adopting a vegan diet for sports. However, the knockout argument against switching to a vegan diet is not because of potential negative effects on performance. Rather it is frequently the perceived discrimination, either subtly or openly [28], that is experienced by vegans but especially vegan athletes in social environments from family members, friends, colleagues at work and school, teachers, principals and educational authorities, training partners, team-mates, coaches and trainers, as well as from so-called nutrition experts and others in various sport-related scenarios and circumstances.

Because of the benefits provided by vegan diets, such a nutritional regimen is worth taking into account in order to achieve the best personal health outcomes not only for non-active people, but also for (young) athletes. Moreover, vegan diets have been found to effectively support parameters that affect physical performance (eg. exercise-induced immunosuppression and oxidative stress due to higher oxygen needs of skeletal muscle), nutritional demands, recovery and resistance to illness of athletes [11,13,16-18,20,24,31,95,198-200,255], [254] (pp. 778,788). Since it has been shown that a well-planned and diligently implemented vegan diet is compatible with athletic performance and success, such diets are healthy options for maximizing performance, endurance, stamina, recovery and regeneration, and immune defenses for athletes involved in heavy training and racing regimens.

In the course of athletic activity, circulation is a key for delivering not only oxygen but also nutrients and other substances relevant to the exercise-induced metabolism (eg. catabolites). Since blood flow is affected by blood viscosity and vascular functions, such as arterial flexibility (eg. diameter thickness, elasticity, compliance) and vasoactivity, these aspects are influenced by diet (mainly by intakes of saturated fat and thus plasma lipid levels), too [16]. Blood viscosity often appears to be increased (hemoconcentration), causing a progressive loss of tissue oxygenation and potentially degrading athletic performance. Long-term aerobic exercise during training and racing results in reduced blood viscosity (hemodilution) due to higher blood volume by higher plasma volume, which promotes performance [255]. In addition to the other advantageous aspects

Table 4: Overview of health advantages to athletes resulting from a well-planned vegan diet[1].

No.	Aspects best providing the prerequisites for performance capacity in sports and exercise (abbreviated)[2]	→	Aspects showing ideal provision of dietary supply in athletes to deliver various benefits, relevant to competitive athletes (abbreviated)[3]
1	↑ Healthiest diet overall, thus best state of health ✓ Good musculoskeletal health ↑ Best health-consciousness ↑ Increased immune function, and thus maximized immune defense (along with less micro inflammation and lower biomarkers of inflammation) ↓ Fewest biological hazards, toxic substances and noxious residues of chemicals from pharmaceutical drugs, industrial toxins, and heavy metals (1:9) in plant vs. animal foods, and least pesticides in plant vs. animal foods (1:14) ↓ Lowest prevalence of allergies; protective against allergic asthma and food allergies ✓/↑ Advantages in prevention of illnesses and diseases, and therapy of sports injuries	→	✓ Good basis for preserving skeletal muscle mass, to build and develop strength and endurance-compatible muscles, and even to increase muscle mass and strength ↓ Lower rates or even no cases of illnesses/sickness and allergies ↓ Shorter or even no periods of sick leave or rehabilitation from sports accidents or injuries, thus least absence from training with no further stagnation or regression in performance level
2	✓/↑ Appropriate provision of energy and nutrients supplied by sufficient intakes ✓/↑ Nutrient-dense but low-calorie ✓ Optimum macronutrient distribution, along with ideal carbohydrate-protein-ratio, and maximal antioxidant status ↑ Best supply of: Carbohydrates, beta-carotine, vitamins C and K, folic acid, magnesium, potassium, fiber, phytochemicals, antioxidants (especially polyphenols) ✓ Equal to or as adequate as non-vegan diets in supply of: Protein, vitamin E, thiamin, biotin, pantothenic acid ✓ Vitamin B12 safely provided by fortified foods, products and supplements ✓/↓ No risk or lower prevalence of deficiencies for key nutrients compared to non-vegan diets (on average 3:7 nutrients deficient) ✓ Optimum acid-base-balance, pH-value, highest alkalizing potential (lowest dietary acid load)	→	✓/↑ Optimal matching of higher energy, carbohydrate, protein and other nutrient demands by higher dietary supply, thus ↑ Enhanced physical potential (at high metabolic rates) ↑ Maximized performance capacity ↑ Gaining advantages over non-vegan athletes considering macronutrient, micronutrient and antioxidant status ✓ Optimum pre-exercise metabolic state (acid-base-balance, pH-value, alkalizing potential/dietary acid load) ↑ Faster replenishment of muscular energy and nutrient stores (increased refueling in-race and post-exercise), thus ↑ Maximized regeneration and recovery process ↓ Shorter time for recovery ✓/↓ Protective against exercise-induced stress, thus lower exercise-induced oxidative stress (aid recovery/regeneration)
3	✓/↑ High quality of plant protein (particularly soy) ✓ Plant protein provides all amino acids ✓ Plant protein beneficial to (sustainable) health ↑ Plant protein healthier than animal protein ✓ Total and daily protein intake (10-12%) is adequate ✓ Plant protein (without the use of additional protein supplements) adequate to meet or exceeded current protein recommendations protein needs at all ages, and higher requirements of athletes (when energy intake is adequate)	→	↓ Diminished muscle soreness, reduced muscle damage and inflammation, better recovery from exercise ✓ Supports protein turnover ✓ Supports metabolic adaptation ✓ Promotes building and maintenance of tissues, increases skeletal muscle mass and muscle strength (hypertrophy) ✓ Remodeling of muscle and whole body protein ✓ Promote repair and renewal of damaged tissue/muscle ✓ Stimulates maximal muscle protein synthesis at rest and post-exercise ↑ Faster or even optimized recovery and/or training adaptations, thus faster regeneration post-exercise

4	✓ Vegan functional foods (sport-specific supplements of concentrated nutrients) to aid dietary strategies in pre-race, in-race and post-race scenarios, are available from various brands and with different flavors	→	↑ Increase in physical performance during race ✓/↑ Promote optimum refueling, maximize restore of body energy stores in-race and post-race, thus aid recovery ↓/✓ Prevent from or reduce gastro-intestinal stress and discomfort, or even aid gastro-intestinal comfort
5	↓ Lower heart rate ↓ Reduced blood viscosity, thus ↑ Improved blood flow ↑ Improved tissue oxygenation, with fast oxygenation of muscles and brain ↓ Reduced heart rate during exercise	→	↑ Enhanced physical potential by ↓ Lower cardiovascular burden already at rest ↑ Gain in adaptive potential to cardiovascular stress especially aids heavy training regimens (high in extent and/or intensity) and heavy in-race burdens at high metabolic rates, along with high cardiovascular stress (higher maximum heart rates)
6	✓ Perception of satiety ↓ Lower BW and BMI ↑ Better BW control/management	→	✓ Achieves, stabilizes and maintains ideal athletic BW specific to the kind of sports and/or discipline, without calorie restriction
7	✓/↑ Protective against mental stress and depression ↑ Better state of mood and mental constitution ✓ Good quality of life	→	✓ Good/optimal for coping with exercise and race-induced stress

[1]Results gathered, accumulated, and condensed from evidence-based data of large-scale cohort studies, epidemiological studies, original research performed on athletic populations, case studies, meta-analysis, review-articles, systematic reviews, prospective cohort studies, interventional studies, and current position statements. BW - Body weight; BMI - Body Mass Index.

[2][13,16-21,24,26,31,84,87,88,94,108,112,113,122,129,141,149,155,156,162,165,170,172,174-176,178,190,198-200,210,211,239-243,249,255,257-259,264,265,308-317,325], [2] (pp. 398, 400, 402, 430), [27] (p. 43), [163] (pp. 15, 65, 67, 74, 77-79), [202] (p. 79), [254] (pp. 778, 788), [326] (pp. 2, 7-8).

[3][2,10,11,13,16,19-21,24,26,31,47,88,95,170,173-176,183,223,237,255,264,266,327], [254] (pp. 778, 788), [326] (pp. 2,7-8).

mentioned above (Table 4 and Figure 1), a vegan diet has been found to improve blood flow and reduce blood viscosity, which in turn reduces heart rate during exercise, accelerates tissue oxygenation of muscles and the brain, and reduces inflammation [16]. Together, a vegan diet may therefore positively influence athletic performance in relation to cardiovascular function, as heart rate is lower at rest, too.

Furthermore, vegans and thus vegan athletes are superior in relation to regeneration and the immune system when compared to non-vegans, resulting from significantly lower inflammation, the stronger immune defense against bacteria and viruses, and the better antioxidant status due to the overall higher nutrient density of vegan diets [11,13,17,18]. Fuhrman and Ferreri [11] concluded that - based on a diet focused on micronutrient-dense whole plant foods which prevents potential deficiencies - vegan athletes can effectively perform at the highest level in endurance sports, which is in line with recent findings and current data [18,20,24]. Due to their high intake of antioxidant (especially carotenoids and polyphenols) rich foods, it is therefore plausible that vegan athletes in particular may have increased protection against immunosuppressive effects (eg. pathogens) following heavy endurance exercise, and consequently suffer less from illness [18]. This nicely matches the findings of both cases of the vegan ultra-endurance athletes, suggesting the greatest immune and anti-inflammatory benefits to occur over ultra-distance and multi-stage events [18,20,198], where the most severe multi-system stress (endocrine and immune physiology and pathology) occurs [256].

In addition to the strongest contribution to overall health, vegan runners currently report the lowest prevalence of allergies (20% vs. 32% and 36% in omnivores and vegetarians, respectively) [24], which matches the sparse data on the protective effect of a diet rich in fruits and vegetables on the occurrence of food allergies [257,258] and allergic asthma [259].

As a consequence, vegan diets are not only advantageous to health, but create a solid basis for athletic performance across all disciplines, since athletic training can be conducted without periods of undesired interruptions due to sick leave or even school, work, and/or training-related disabilities.

The most important advantages of vegan diets for athletes arise from the low-energy, nutrient-rich and high-carbohydrate nature of plant foods (displayed in Figure 2), which illustrates how to fuel correctly to generally aid a healthy constitution, which is a prerequisite for completely tapping one's athletic potential to perform [11,26,88], [163] (pp. 14-15).

According to the WHO [260,261], based on adequate food choices, a healthy BW can be sustainably maintained over a lifetime. In terms of maintaining a stable BW as a

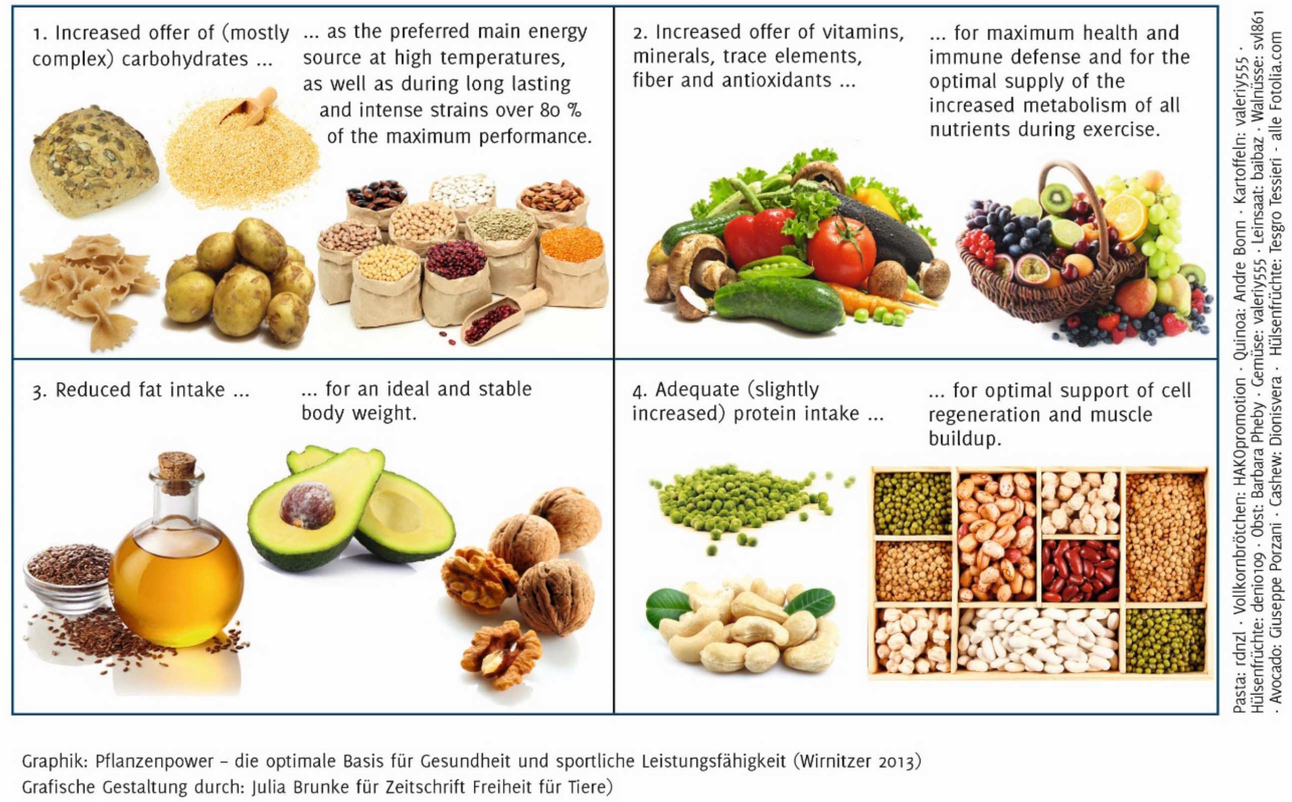

Figure 2: Main advantages of plant foods, which provide the basis for excellent health and athletic peak performance [23]; graphic design by J. Brunke.

performance-determining factor in competitive sports, and since vegan diets most effectively reduce BW due to a reduction in body fat [93,97,98,128,129,262,263], [202] (pp. 43-45), as well as reduced metabolic and atherosclerotic risk [16], switching from a mixed to a vegan diet is the most promising solution for ambitious and serious athletes.

BW is one key factor affecting an athlete's potential for sporting success and is a predictive factor for performance in various kinds of sports and disciplines [174]. For example, disciplines with BW classifications like karate, judo and boxing, or technical and body conscious sports with a complex physiological profile such as gymnastics or ski-jumping, among others, but particularly for endurance sports (running and cycling, both uphill too). As endurance, speed and power performance are significantly associated with a lean body (eg. better muscle to fat ratio), BW/BMI is generally accepted as a key factor in performance, because the elimination of excess fat improves predictive statistics such as the power-to-weight ratio or VO_2 max relative to BW [174,264].

One study has compared non-active vegans (low-calories, low-protein) with endurance runners and healthy subjects, with omnivorous control groups matched (age, gender, height) against the vegan subjects. It was found that to be as slim and fit as non-active vegans, omnivores would have to run almost two marathons a week for a period of 21 years [71]. Other current findings have shown vegan endurance runners to be significantly leaner than omnivores (64 kg vs. 68 kg; p = 0.001), with vegans having the highest BW/BMI scores, which contribute to overall state of health (69%) [24]. Moreover, being leaner may promote endurance performance resulting due to better aerobic capacity at both maximal and submaximal levels, along with other performance-determining factors [16].

It is common practice for athletes to starve themselves to reduce or maintain a low BW by counting calories, eating less (caloric restriction), or adopting harmful to dangerous dietary regimens that contain imbalanced nutrients, so that they can perform better or at their best. Instead of creating optimal BW conditions for a specific kind of sport or discipline, such dietary habits can negatively affect performance due to imbalanced energy supplies. The effective intervention, namely using (complex) carbohydrates as the main fuel instead of higher protein intake, is often neglected (eg. low carbohydrate, paleo or keto diets), which is clearly detrimental to health and athletic performance from a long-term perspective. A dietary strategy that is restricted in energy and nutrients cannot be successful over long-term athletic careers, even if it is common behavior.

Within the context of BW control, exercise-induced calorie intakes should be supplied by a healthy selection of nutrient-dense but simultaneously low-calorie foods [202] (pp. 67-77, 79), [265] (pp. xv, xxiii-vi), which perfectly matches the low-fat, high-fiber characteristics of plant foods, since a high intake naturally assists in BW control. On this basis, the "Eat more - weigh less" approach [265], when it is realized through a whole food vegan diet, would encapsulate the most successful aspects of BW management, and has been frequently confirmed as being the most effective intervention to stabilize a healthy BW. A wholesome vegan diet (adequately supplemented by vitamin B12) constitutes the optimal sports diet for an athletes' long-term health and BW management in order to adequately fuel for training and competition.

From the experience of two decades of working with motivated amateur and professional athletes, and of advising how to sustainably switch to and maintain (if not a lifetime adherence to) a healthy sport-specific vegan diet, it has been frequently observed that some kind of imbalanced dietary behavior, and/or energy restriction, even sports-focused starvation, is a common habit in relation to BW management in order reduce and keep down an athlete's weight. However, the supervised athletes reacted positively to background information and to putting a vegan diet without calorie restriction into practice, not least because vegan functional foods and products (sport-specific supplements of concentrated nutrients) are available from a variety of brands and with different flavors. These are known to benefit dietary strategies in pre-race, in-race and post-race scenarios, eg. to enhance race performance, support and/or accelerate refueling and recovery (ie. during stage races), but even to prevent or reduce gastro-intestinal stress and discomfort. Moreover, athletes wish to avoid having illness-induced breaks and interruptions in training and missing important events in the race season. The advantages of a healthy vegan diet help to prevent such sick leave.

Table 4 presents a summary (without claiming to be complete) of the various advantages to athletes that emerge from a vegan diet relating to good health, and thus provides a solid basis for athletic performance capacity to be developed and to tap full athletic potential. Together, these benefits result in aspects that effectively support parameters that have been demonstrated to positively influence exercise performance.

To close, as a reflection of the growing scientific interest in vegetarian kinds of diet in relation to their potential for enhancing or hampering sports performance, a brief/short outline of the recent focus on vegetarian and vegan diets in sports affecting both anaerobic and aerobic exercise performance is given. This includes dietary antioxidants and exercise-induced oxidative stress [18,211,266,267]; kinds of plant protein such as soy, rice, pea, hemp, and wheat [268-270]; creatine [271,272], l-carnitine [273,274]; muscle carnosine [275]; and dietary nitrate supplementation from beet root juice for example [276-278], among others [2] (p. 426).

Conclusions

Currently there is a boom in vegan diets in the public and in sport. Against the background of health-oriented action competence and sustainable action readiness, this manuscript aims to provide an evidence-based rationale about the benefits for (young) athletes and coaches thinking about adopting a vegan diet. This review is novel, as it is the first to link scientific evidence to relevant anecdotal information on sport and vegan diets, but also bridges the gap between, translates and applies the rationale from excellent science to practical implications of this dual approach in settings of everyday life. It should support vegan athletes in their desire to adopt the most sustainable diet for their health as a condition for performance.

Based on an abundant body of scientific evidence about vegetarian and vegan diets in relation to health, it has been proven that the tremendous health benefits delivered by vegan diets are compatible with health and form a prerequisite for sports performance. A well-planned vitamin B12 supplemented and diligently implemented vegan diet promotes building muscle mass and strength, and a good state of health for athletes. Moreover, on this solid basis, vegan diets applied to sports-related dietary tactics are compatible with high performance and competitive sports, too. In this context, questions raised about adopting and integrating this highly effective, low-cost intervention in an athlete's daily schedule will be addressed, including why vegan diets still have not found practical application in performance sports, both on a larger scale and to a greater extent.

However, research about the effects of long-term or even lifetime adherence to veganism on athletic performance is still very limited to only two case studies performed on ultra-endurance athletes. Moreover, to date the comparison of data is difficult due to the great variations between original research in addition to the very small body of scientific data of vegan diets related to sport. This is all the more supported by the fact that not every result from literature searching is a meaningful match, as found when searching for "vegan" and "sport" in the PubMed database [279], with only 13 matches (out of total 43 hits) that fit the sense of the key words.

To conclude, if an athlete expresses his/her intention to switch and adhere to - or even only wishes to test - a vegan diet, the knowledge that vegan diets are compatible with (possible peak) performance has the potential to encourage (young) athletes and their families, teachers, coaches and dietitians, scientists (sport, nutrition), primary and family care physicians, specialist physicians (sport and/or nutrition medicine), but also experts, decision makers, multipliers and role models in health and education to do so, based on sound recommendations. In this regard, and since schools and sports clubs are training grounds for the recruitment of young athletes, the respective curriculum providing scientific-based knowledge didactically and age-appropriately at kindergarten, then grade school and up to university education is recommended. In particular, studies on nutrition, medicine, and generally studies regarding teacher education, health and life sciences (eg. pedagogy, sports science, biology) as well as courses for health professions, should provide introductory lectures on the huge potential of health effects of vegetarian but particularly vegan diets. This should be further supplemented by advanced lectures and specialized seminars to focus on in-depth issues and specific details (eg. nutritional medicine, sports medicine), along with the cumulative effects that emerge from the approach of the interdisciplinary field mentioned before.

Future perspective

Although the number of vegans and vegan athletes is increasing globally, it still remains difficult to find a larger group of vegan athletes participating in the same event to provide a sufficiently large sample to conduct a meaningful study. Therefore, the authors emphasize the importance of, as well as the need for future research with a specific focus on the effects of a long-term adherence to veganism in particular, for exercise performance on the following issues to allow for better comparison of data:

- Clear distinction between vegetarian and vegan subgroups with specifically defined food items allowed/restricted.
- Clear distinction between specific athletic populations, meaning specific kinds of sports and even sports disciplines, such as endurance and strength athletes from specific disciplines.
- Studies performed on large sample sizes, like the NURMI Study with more than 3,800 participants (Step 1).
- Studies performed on long-term veganism if not life-long adherence of veganism in athletes.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Availability of Data and Material

Not applicable.

Competing Interests

The author declares that there is no competing interest.

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Authors' Contributions

KCW developed the original idea, conceptualized and designed the study, drafted and wrote the manuscript, and critically revised it.

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Authors' Information

KCW lectures and researches at the interface of sport, vegan nutrition and sustainable health. The transfer of scientific knowledge into practice-related settings such as sports, (high-)school, and university/college, and its expression as health-orientated individual and public health actions, is of special concern to her. From Science 2 School: Sustainably healthy – active & veggy, as follow-up of the NURMI Study, started in Oct 2019 and addresses more than 860,000 pupils and teachers/principals at 2,668 schools in Austrian secondary level I and II.

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