PLANT-BASED DIETS AND ATHLETIC PERFORMANCE

– Written by Nanci S. Guest, Canada and Heidi Lynch, USA

INTRODUCTION

With the growing interest in the benefits of plant-based diets, it is relevant to consider whether plant-centered dietary approaches may influence athletic performance. Reasons for adopting plant-based diets include health benefits, religious or cultural practices, environmental and climate factors and ethical concerns for animals[1,2]. This review outlines which nutrients may differ between plant-based (PB) and omnivorous diets and how this may impact exercise performance. In addition, the use of nutritional supplements for general health or performance enhancement through selected ergogenic aids in those following PB diets will be covered briefly.

Athletes' dietary patterns range substantially in the degree of inclusion vs. the limiting or avoidance of animal-sourced foods (ASF). Although some advocate for the term "plant-based" to be used interchangeably with "vegan"[3], which is a diet that is exclusively derived from plants, this review will use the term "plant-based" to mean a diet based on "all" or "mostly" plants. PB diets are most widely understood as diets where ASF are consumed infrequently (e.g. <10-20% total energy intake), similar to vegetarian diet. In comparison, "vegan" or "veganism" is characterized as a justice movement and lifestyle that not only includes a strict PB diet, but also excludes the exploitation of animals in any form (e.g. clothing, entertainment). Accordingly, all vegans consume a PB diet but not all PB eaters are vegan.

IMPACTS TO HEALTH AND PERFORMANCE

PB diets are increasing in many western countries due to the growing recognition of their ability to lower the risk of many diseases[1]. Studies consistently report reductions in cardiovascular disease[4], hypertension[5], diabetes[6], obesity[7] and several cancers[8-10] in those following PB diets. Analyses of the human microbiome after adoption of a PB diet have also revealed mechanistic insight into the benefits of plant-derived nutrition on microbiota diversity and populations[11,12]. Prioritizing the health of the gut microbiome, through whole-foods PB diets, may also offer a targeted therapy for high-intensity training athletes to improve metabolic, immune, and gut barrier function[13].

Potential mechanisms linking a diet high in PB foods to improved athletic performance are limited, but not absent[14-16]. Importantly, reports show that PB eating patterns neither improve nor hinder physical performance [17,18]. Indeed, in a review of eight studies no acute differences were found between a PB diet and an omnivorous diet in muscular power, muscular strength, anaerobic or aerobic performance[17]. Similarly, studies suggest that PB diets do not compromise endurance performance[19] and may facilitate aerobic capacity in athletes[20].

More recent findings also reported that a PB diet was not detrimental to endurance and muscle strength, and even showed superior submaximal endurance in vegans compared with omnivores[16]. It also appears that muscle and strength development with resistance training is supported by plant-sourced proteins to the same degree as ASF[21-24], with even stronger support at ingestions rates of protein reaching ~1.6 g/kg/day[24,25]. In summary, based on the results of aforementioned studies, it appears that a PB diet can be a suitable option for athletes.

The notion that a diet high in plant foods may offer performance benefits appears to have some merit and plausibility on several fronts[15]. Through higher fiber content and lower caloric density, PB diets have consistently been shown to reduce lower body fat[26,27], which is a key performance goal in athletes to optimize body composition[28]. Due to the high carbohydrate content in PB diets, they foster effective maintenance of glycogen levels[29]. By reducing blood viscosity and improving vascular flexibility and endothelial function, PB diets may be expected to improve skeletal and cardiac tissue blood flow and oxygenation[15]. Vegetables, fruits, nuts, seeds, legumes and grains are packed with phytonutrients that

Table 1

Food (serving size)	*Protein (g)*
Seitan, cubed (1/3 cup)	*21*
Tempeh (1 cup)	*20*
Edamame (1 cup)	*19*
Lentils, cooked (1 cup)	*18*
Black beans, cooked (1 cup)	*15*
Tofu, extra firm (0.2 block)	*10*
Soymilk, original and vanilla (1 cup)	*7*
Chia seeds (1 oz)	*5*

Table 1: Protein content of select food items.

have antioxidant and anti-inflammatory properties[14,30]. This can lead to reduced oxidative stress and inflammation, and thus, enhanced endurance performance, reduced muscle damage, boosted immunity and more efficient recovery from training and competition[14].

The comparability of PB diets to those higher in ASF with regard to performance along with the well-established health, environmental and ethical benefits of PB diets, make it an appealing choice for many athletes[18]. As with omnivorous diets, there are certain nutrients in PB diets that merit extra planning and attention to optimize health and performance for athletes.

NUTRIENTS TO CONSIDER

Protein

Historically, meat and other animal-derived proteins have been viewed as an integral component of athletes' diets, leading some to question the adequacy of PB diets for supporting muscle growth and exercise performance in athletes and active individuals.

It is commonly thought that protein intake may be inadequate in PB diets. As we and others have argued[22], the amounts and proportions of amino acids consumed by vegetarians and vegans are typically more than sufficient to meet and exceed individual daily requirements, provided a reasonable variety of foods are consumed and energy intake needs are being met[22,31]. The terms complete and incomplete are misleading in relation to plant protein. Ingesting protein from a variety of plant foods, over a 24-hour period, supplies enough of all indispensable (essential) amino acids when energy requirements are being met[32].

The Recommended Dietary Allowance (RDA) is 0.8 grams of protein per kilogram of body weight; however, the Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine[33] suggests that athletes should consume 1.2-2.0 grams of protein per kg to support the body's adaptations to exercise and increased protein turnover due to training. As with the RDA, no unique recommendation is given for athletes following vegetarian or vegan diets. As long as athletes consume adequate energy (kcal) from a well-balanced diet, vegetarian and vegan athletes should be able to consume the recommended amounts of protein through their diet[34].

Several studies examining the dietary intakes of vegan and vegetarian endurance athletes have shown that these athletes are meeting their recommended daily protein[19,20]. Food sources high in protein that are acceptable to sport-focused individuals following PB diets include soy products (tofu, tempeh, edamame, soymilk), pulses (beans, lentils, peas) and an array of plant-based meat substitutes and protein powders. Seeds, nuts, and whole grains, such as quinoa, and plant-based milks also contribute protein to the diet (see Table 1).

Omega-3 Fats

Omega-3 fats may influence the preservation of strength and enhance recovery from heavy exercise through their anti-inflammatory effects[35]. The omega-3 fatty acid biosynthesis pathway converts α-linolenic acid (ALA) to eicosapentaenoic (EPA) acid and further into docosahexaenoic acid (DHA, integral to the visual process and synaptic functioning). ALA is found mainly in nuts, seeds and plant oils, and DHA and EPA are found in fish and other seafood[36]. While intakes of ALAs are generally higher in those following PB diets compared to omnivores, intakes of EPA and DHA are low in PB diets and virtually absent in vegans or strictly PB diets[36]. Despite the assumptions that PB eaters/vegans are at risk of deficiency due to low conversion of ALA to EPA and then to DHA[37], there does not appear to be evidence of deficiencies in adults[38]. Moreover, some studies have shown vegans to have higher circulating DHA levels, with zero consumption, compared to fish-eaters[39], likely due to higher than average intakes of ALA. This finding, along with new findings and hypotheses on ALA/EPA supplementation and conversion to DHA[40,41], highlight the likelihood that PB eaters can maintain their serum DHA levels through consumption of ALAs only. There is no current RDA for EPA or DHA; therefore, those following a vegan or PB diet should focus on consuming adequate amounts of ALA (see Table 2) which may be higher than the RDA[42] or obtain DHA directly through algal supplementation[42].

Vitamin B12

Vitamin B12 (cobalamin) is important for normal brain and nervous system functioning and helps to make DNA[43]. Vitamin B12 is also associated with red blood cell (RBC) formation and low levels may result in megaloblastic anemia[44]. Megaloblastic anemia limits the blood's oxygen carrying capacity, thus reducing its availability to cells, which may negatively impact aerobic performance[44]. Individuals following PB diets must take particular care to consume enough vitamin B12, as it is mainly found in meat, eggs, and dairy products. Despite some reports in popular media, studies on naturally occurring and Vitamin B12-containing plant-derived food sources show that only nori (seaweed), is suitable as a Vitamin B12 source for vegetarians[45,46]. However, due to inconsistencies and variability in plant sources of B12 content, the only reliable and recommended PB/vegan sources of B12 are fortified breakfast cereals and nutritional yeasts, PB meat substitutes, PB milks and other fortified PB food products[47]. Those following a PB or vegan diet should take a B12 supplement and track intakes derived from B12 fortified foods[34,47].

Iron

The importance of iron to athletes is established through its biological role in supporting the function of proteins and enzymes essential for maintaining physical and cognitive performance[48]. Iron is incorporated into hemoglobin and myoglobin, proteins responsible for the transport and storage of oxygen[49]. Iron-deficiency anemia is the most common type of anemia among athletes, who have higher iron requirements due to increased erythropoietic drive through higher intensities and volumes of training[50]. The female athlete is at particular risk of iron deficiency due to menstruation and generally, a lower total energy or food intake compared to males[51]. Owing to a diet rich in whole-grains and legumes (good iron sources), both PB and vegans consume similar amounts of iron as omnivores[27,52]; however, the risk of iron deficiency is greater due to low bioavailability of iron from plant foods[53]. Accordingly, recommended iron intakes for individuals following PB or vegan diets are 1.8 times higher than for omnivores who consume ASF[53]: 32 mg/day (vs. 18 mg/day) for premenopausal adult women and 14 mg/day (vs.8 mg/day) for adult men and postmenopausal women. Table 3 displays iron content of selected plant-based foods.

Zinc

Zinc serves as a catalyst for many enzymes in the body, is involved with cell differentiation and proliferation, and helps to regulate gene expression. It is also important for immunity[54]. Plant-based sources of zinc have lower bioavailability due to the presence of phytates (which are in legumes and whole grains) that bind zinc and inhibit its absorption[55]. Because of this reduced bioavailability, vegetarians may require 50% more zinc compared to omnivores[48]. This equates to male

Table 2

Food (serving size)	*ALA (g)*
Flaxseed oil, 1 tbsp	7.3
Chia seeds, 1 ounce	5.1
English walnuts, 1 ounce	2.6
Flaxseed, whole, 1 tbsp	2.4
Canola oil, 1 tbsp	1.3
Soybean oil, 1 tbsp	0.9
Black walnuts, 1 ounce	0.8

Table 2: Alpha-linoleic acid (ALA) content of select food items.

Table 3

Food (serving size)	*Iron (mg)*
Lentils, cooked (1 c)	6.0
Chickpeas, cooked (1 c)	5.2
Tofu (1/2 block)	3.7
Black beans (1 c)	3.6
Quinoa (1 c cooked)	2.8
Pumpkin seeds (1 oz)	2.3
Cashews (1 oz)	1.7
Dried apricots (1/4 c)	0.9
Spinach (1 c raw)	0.8
Hemp seeds (1 T)	0.8
Dried figs (1/4 c)	0.8
Chia seeds (1 T)	0.6
Kale (1 c raw)	0.4

Table 3: Iron content of select foods.

Table 4

Food (serving size)	Zinc (mg)
Chickpeas, cooked (1 cup)	2.5
Pumpkin seeds (1 oz, without shell)	2.2
Lentils, cooked (1 cup)	1.3
Tempeh (3.5 ounces)	1.1
Tofu, extra firm (0.2 block)	1.0
Almonds (1 oz)	0.9
Whole wheat bread, 1 medium slice	0.6

Table 4: Zinc content of select food items.

Table 5

Food (serving size)	Calcium (mg)
Low oxalate content, high absorption rate (~50%)	
Turnip greens, raw (1 cup, chopped)	104
Chinese cabbage, raw (1 cup, shredded)	74
Kale, raw (1 cup)	53
Moderate absorption rate (~30%)	
Soymilk, original and vanilla (1 cup)	299
Tofu, extra firm (0.2 block)	257
Lower absorption rate (~20%)	
White beans, cooked (1 cup)	161
Almonds, unsalted (1 oz)	74
Tahini (1 tablespoon)	64
Oranges (1 fruit)	61
Figs, dried (1/4 cup)	60
High oxalate content, lowest absorption rate (~5%)	
Beet greens, raw (1 cup)	45
Spinach, raw (1 cup)	30
Swiss chard, raw (1 cup)	18

Table 5: Calcium content, absorption rate, and oxalate content of select food items.

*data from Food Data Central using SR Legacy entries: https://fdc.nal.usda.gov/. Data are rounded to the nearest tenth. Oxalate content and absorption rates based upon[33].

vegetarians needing 16.5 mg of zinc and female vegetarians needing 12 mg of zinc daily. Some preparation techniques that increase the bioavailability of plant sources of zinc include soaking and sprouting beans, nuts, seeds, and grains; leavening (bread has more bioavailable zinc compared to crackers); and using organic acids with zinc such as citric, malic, or lactic acid[34,56]. Some researchers suggest supplementation may be advisable for vegan athletes[57], but this is not universally agreed upon. Soy, legumes, grains, seeds, nuts, beans, and fortified cereals are acceptable zinc sources for vegans and vegetarians. Table 4 provides a list of some zinc sources.

Vitamin D

Vitamin D plays a critical role in regulating bone density by influencing calcium and phosphate absorption, and it also plays a role in immunity[58]. Currently the RDA for males and females ages 19-50 is 600 International Units (IU) per day[59]. Vitamin D is not found naturally in many foods. The International Olympic Committee consensus statement on dietary supplements and the high-performance athlete suggests that vitamin D supplements are commonly required for athletes (not just for vegetarians)[60]. Sufficient skin exposure to sunlight is an important source of this nutrient[61]. Factors affecting how much vitamin D is synthesized by the skin's exposure to sunlight include skin pigmentation, and amount and intensity of sun exposure, which is affected by the time of day, season, and latitude[62]. About 10-15 minutes of skin exposure to the arms and legs should be sufficient to produce enough vitamin D[62]. Research has shown no significant differences between vegetarians and omnivores with respect to serum 25-hydroxyvitamin D status[63]. Food sources providing vitamin D include UV-irradiated mushrooms and fortified foods such as plant-based milks, orange juice, and cereals. It has been suggested that it may be beneficial for athletes to supplement 1,000-2,000 IUs/day, particularly if the athletes have minimal sun exposure[61].

Calcium

Like vitamin D, calcium is critically important for optimizing bone health. It helps maintain the integrity of the skeleton as part of hydroxyapatite. Additionally, calcium is involved with muscle contraction, vasoconstriction and dilation, hormonal

The amounts and proportions of amino acids consumed by vegetarians and vegans are typically more than sufficient to meet and exceed individual daily requirements.

responses, and the nervous system[59]. The RDA for males and females ages 19-50 is 1,000 mg per day[59]. Vegetarians who include dairy in their diets tend to consume similar amounts or more calcium compared to omnivores, although people who follow vegan diets tend to consume less calcium[27,52,64]. Plant sources of calcium may be less bioavailable due to the presence of oxalic acid[59] and to a lesser extent, phytates and fiber[34]. The International Olympic Committee consensus statement on dietary supplements and the high-performance athlete notes that, as with vitamin D, calcium is a nutrient that often needs to be supplemented for athletes, regardless of their dietary pattern[60]. Table 5 presents calcium content and approximate absorption rate of select foods.

Ergogenic Aids

Increased muscle creatine content can help athletes generate quick, explosive movements at high intensities, enhance performance in strength and power events, and help to increase muscle mass by supporting increased volumes of resistance exercise[65]. Dietary intake of creatine is low or absent in individuals following a PB or vegan diet[66]. It was assumed that PB eaters who exclude dietary creatine sources and have lower muscle creatine storage[67] would experience greater ergogenic benefits. However, a recent systematic review[66] found that creatine supplementation increased various parameters of performance in vegetarians and omnivores equally. Furthermore, the amount of creatine that is used in supplemental form to improve performance is 5 g per day as a maintenance dose, and 20 g per day for ~7 days as a loading dose, which cannot be practically achieved through dietary intakes alone. For example, an individual would have to consume 35 oz of beef, salmon or pork per day to reach the recommended daily maintenance dose of creatine for ergogenic goals of 5 g per day[66].

Muscle carnosine also tends to be lower in vegetarians compared to omnivores[68]. Carnosine is found in skeletal muscle and the central nervous system, and is synthesised in situ from its rate-limiting precursor β-alanine[69]. There does not appear to be a significant relationship between dietary β-alanine consumption and muscle carnosine content[68]. Meat and poultry are the main sources of β-alanine in the diet, and β-alanine supplementation has been shown to increase muscle carnosine concentrations, benefiting high-intensity exercise performance by buffering excess hydrogen ions which can lead to premature fatigue[70]. Similar to creatine, the amount of β-alanine that is used in supplemental form to improve performance is 1.6 to 6.4 g per day for several days prior to an event, and an individual would have to consume up to 24 oz of poultry per day to reach the equivalent β-alanine dose required to enhance performance[68].

In summary, well-designed PB diets that include some fortified foods, can provide adequate macro- and micro-nutrient intakes in athletes and active individuals to support health and performance. Abundant choices in the marketplace offer convenience and a variety of fortified food products and supplements for those choosing to follow a PB diet. Athletes should be taking extra care to plan out their sport nutrition strategies whether they choose to follow a strict or mostly PB diet, or an omnivore diet.

Overview of the major food categories in a plant-based diet, with examples

- **Fruits:** any type of fresh, frozen, or dried fruit including berries, apples, bananas, grapes, strawberries, citrus fruits, avocado etc. Dried fruits including figs, dates, raisins, apricots and others.
- **Vegetables:** plenty of veggies including peppers, broccoli, corn, asparagus, avocados, lettuce, spinach, kale, peas, collards, and others.
- **Tubers:** root vegetables like potatoes, carrots, parsnips, sweet potatoes, beets, and others.
- **Whole grains:** grains, cereals, popcorn and other starches in their whole form, such as quinoa, brown rice, millet, whole wheat, oats, barley, and others.
- **Nuts, Seeds & Oils:** walnuts, almonds, cashews, brazil nuts, peanuts, and pumpkin, hemp, flax and chia seeds. Olive, pumpkinseed, sunflower, soybean, canola, avocado and sesame oil and others.
- **Legumes:** beans of any kind, lentils, pulses, and soy.

References

Available at www.aspetar.com/journal

Nanci S. Guest Ph.D., R.D., C.S.C.S.
Post-Doctoral Research Fellow
Department of Nutritional Sciences
Faculty of Medicine, University of Toronto
Toronto, Canada

Heidi Lynch Ph.D., R.D.N.
Associate Professor
Point Loma Nazarene University
San Diego, USA

Contact: nanci.guest@mail.utoronto.ca

Sample menu

"At Risk" Nutrients: protein, iron, calcium, ALA and zinc meet requirements for an 80 kg (176 lb) male multi-sport athlete
Nutrients needed: 128 g PRO (based on 1.6 g/kg), 14 mg iron, 1000 mg calcium, 2.1 g ALA, 11 mg Zn

Sample menu providing 130 g protein (vegan)	Sample menu providing 22 mg zinc (16.5 mg amount recommended for male vegetarian or vegan)	Sample menu providing 1100 mg of Calcium
Breakfast: (32 g)	**Breakfast: (6 mg)**	**Breakfast**
Smoothie made with:	1 cup oatmeal (3 mg)	1 sesame bagel (160 mg)
1 scoop protein powder (20 g)	1 cup soymilk (0.6 mg)	2 T almond butter (80 mg)
1 banana (1 g)	1 oz pumpkin seeds (2.2 mg)	1 navel orange (80 mg)
1 c mixed berries (1 g)	1 c blueberries (0.2 mg)	12 oz calcium-fortified plant milk (500+ mg)
2 T flaxseed (3 g)	**Snack: (2.5 mg)**	**Lunch**
1 c soymilk (7 g)	1 cup chickpeas toasted with Moroccan spices	2 slices whole wheat bread (100 mg)
Snack: (22 g)	**Lunch: (6.3 mg)**	1/4 cup hummus (15 mg)
1 c edamame (19 g)	1/2 block tofu (2.5 mg)	2 slices tomato (5 mg) and 1/4 cup sliced cucumber (5 mg)
6 whole grain crackers (3 g)	1 cup brown rice (1.4 mg)	Banana (5 mg)
Lunch: (30 g)	1 c shitake mushrooms (0.8 mg)	**Snack**
2 slides whole wheat bread (9 g)	1 cup broccoli (0.4 mg)	Apple (10 mg) with 2 T peanut butter (20 mg)
1/3 c seitan (21 g)	1/4 cup peanuts (1.2 mg)	**Dinner**
Lettuce	**Snack: (0.8 mg)**	Stir fried vegetables: 1 cup tempeh (180 mg)
Tomato	2 T almond butter (0.5 mg)	1/2 cup broccoli (30 mg), 1/2 cup carrots (20 mg)
Snack: (10 g)	1 peach (0.3 mg)	1 T sesame seeds (90 mg)
1/2 cup hummus (9 g)	**Dinner: (4.6 mg)**	1 cup brown rice (5 mg)
1/2 cup carrots (0.5 g)	1 cup lentils (1.3 mg)	**Snack**
1/2 cup cucumber (0.4)	1 cup barley (1.3 mg)	2 T almonds (100 mg)
1/2 bell pepper (0.4)	1/2 avocado (1.3 mg)	1 cup sliced peaches (10 mg)
Dinner: (27 g)	1 cup asparagus (0.7 mg)	
1 cup lentils in simmer sauce (18 g)	**Snack: (1.7 mg)**	
1 cup quinoa (8 g)	1 cup blackberries (0.8 mg)	
1/2 cup broccoli (1 g)	1 oz dark chocolate (0.9 mg)	
Snack: (15 g)		
1 cup nondairy yogurt (9 g)		
1/4 cup almonds (6 g)		

* T=Tablespoon; c=cup