RETRACTED ARTICLE: Effect of vegan diet (VD) on sports performance: a mechanistic review of metabolic cascades

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ABSTRACT
Sportsmen may choose to include vegetarian diet in their dietary regime for a variety of ways like its beneficial health impact, due to religious restrictions or to protect animals for environmental integrity. These diets are loaded with a wide variety of phytochemicals with superior health benefits safeguarding against chronic diseases. Besides their role in health management these foods also play a key role in enhancing different sports performances owing to contained with instant energy providing carbohydrates that are crucial for competitive sports performance. Furthermore, they are also richly enriched with antioxidants that are essential for high-end sports performance. However, few vegetarian diets are the source of anti-nutritional entities like high fiber content, chelating agents, phytates, and tannic acid. These interfere with the bio-availability of crucial dietary components like iron, zinc, proteins. Therefore, a sound nutritional approach is required while planning plant-based dietary regimes for sports performance. This review will systematically focus on the impact of vegetarian diets on sports performance in the light of currently available research findings in this field to provide a guiding hand to sports specialists and nutritional experts in planning the vegetarian dietary plans for optimizing the sports performance. In addition, this review explains the bio-availability and enhancement strategies of different vegetarian diet-based nutrients through different energy metabolism pathways.

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Introduction
Vegetarian diets (VGD) disallow all animal-based meals (meat, poultry and fish). They can be further classified as vegan diets (VD) in which individuals stay away from foods derivative from animals, such as milk foodstuffs and eggs. Vegan diets are popular for a variety of reasons. These might vary from ethics to the environment, but they can also come from a desire to enhance one’s health. Lacto-ovo-vegetarian if they still consume dairy and eggs, as well as lacto-vegetarian or ovo-vegetarian if they just consume dairy and eggs, respectively, as animal-derived products.

Even though a vegan diet (VD) is not appropriately interpreted in the literature in terms of nutrient and food content, it generally tells us that there is a variation in dietary patterns that shows the higher intake of plant and plant-based foods and almost completely restriction on animal and animal-based

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products, even though milk and eggs are not allowed in VD.\cite{1} There is a certain level of restrictions regarding these diets such as avoiding red meat to the avoidance of animal and animal products completely. It is reported that the proportion of the population that is following VD is increasing with an estimate of 5–10% in developed countries.

There are plenty of logical reasons to follow VD. Generally, a stimulus to follow these diets such as moral values (animal welfare), health advantages, religious beliefs, or several other environmental disturbances (less land, water, greenhouse gas emissions, and energy utilization in contrast to livestock farming), to follow managed VD generally or for especially health concerned population (CVDs, cancer, etc.) is effective and potentially better than omnivorous diet in reducing the spread rate of life style related diseases like hypertension, obesity, type 2 diabetes, metabolic syndrome, and some cancers.

In spite, of there being plenty of evidence that VD is good for health but there remain some suspicions that VD may affect performance in sports. VD with the inclusion of dairy or dairy products commonly may ensure a sufficient supply of almost all nutrients needed for good human health and performance, however in some cases diets lacking the inclusion of other animal sources still are deficient in micronutrients, including omega-3 fatty acids, calcium, and B12 vitamin, which are not only important for human health but also for sports activity. However, taking a variety of plant-based foods with an adequate dietary plan is important to fulfill all dietary needs not only for the whole life but also from the athletic performance point of view. In this article, the impact of vegan diet will be discussed for its beneficial role on overall health and wellbeing, with special reference to its role in supporting sports performance. Moreover, recommendations are given to follow in diet plan for athletes avoiding meat and meat products.

**Health impact of vegetarian diet**

The nutritional quality of VD is below the range compared to other diets, such as processed foods that are altered nutritionally and many other whole food sources that are rich in nutrients. There may be fewer chances of the occurrence of chronic diseases while taking well-managed VD, or there may be more chances of occurrence of diabetes,\cite{2-4} and cardiovascular disease while taking VD rich in processed foods.\cite{5-8} From these arguments, we can say there is no difference between an animal-based diet and a VD in terms of diet planning, so there must be need for attention that providing a nutritionally adequate diet for individuals who are eager to maintain their bodies for fitness.\cite{9}

It has been elucidated in a systematic review by\cite{10} that there are fewer chances of early death by ~80% of those individuals who are consuming a diet rich in fish, fruits, legumes, vegetables, nuts, and whole grains and reduced intake of red and processed meat (not the avoidance hereof) and sugar-sweetened drinks compared to intake from the riskier type of foods. Another critical review by\cite{9} states that antioxidant and polyphenolic properties of vegetables and fruits alone can diminish the risk of many disorders because these compounds have an impact on cellular redox reactions, inflammatory responses, endothelial transport, and metabolic processes, all these processes are involved in the pathophysiology of plenty of diseases. An umbrella study by,\cite{11} demonstrates that more consumption of a variety of fruits and vegetables has promised shielding effects in case of varying levels proof in many disorders. It is believed that high fiber content in VD is more beneficial for microorganisms that are present in the gut.\cite{12-14} So, there may substitute a part of an individual’s animal and animal-based product intake with that of plant-based sources that may elevate the quality of an individual diet with increased, polyphenols, antioxidants, and fiber content while intake of less desirable fats decreasing intake of energy.\cite{15-17}

Whilst it is explored the effects of a strict VD in some randomized controlled trials, it is also found that substituting a portion of animal and animal-based products with that plant-based foods in many epidemiological studies.\cite{18} These strategies have exhibited benefits related to morbidity, mortality, and prevention which are linked to many chronic diseases.\cite{19} Although, it is suggested in much research related to clinical conditions that there should be included more vegetables, fruits, and whole
grains in the meal without abandoning animal and animal-based products. In addition, plenty of proof in favor of VD arises from epidemiological research, and there couldn’t estimate the cause-effect relationship.\[20,21]\n
**Impact of vegetarian diet on nutrient absorption**

Due to the reduced bioavailability of nutrients from a vegetarian diet, some individuals may suffer from energy and nutrient deficits because a vegan diet is not properly planned.\[22–24]\n
Nuts, oilseeds, grains, and pulses are common sources of anti-nutritional factors such as tannic acid, phytic acid, and fiber in vegetarian diets.\[25]\n
They can impair the absorption rate of some key nutritional components, although they can also be helpful. (See Figure 1) Plant-based protein quality should also be considered in this context.

**Tannic acids**

In foods including cereals, nuts, fruits, pulses, beans, and beverages such as coffee, wine, and tea the astringent polyphenolic molecule known as tannin can be found in abundance. Complexes formed by tannic acids in the gastrointestinal tract reduce the absorption and utilization of nutrients, such as vitamins and minerals, by binding to proteins, carbohydrates, or digestive enzymes in the digestive tract. However, tannin ingestion has anti-oxidative, anti-microbial, anti-inflammatory, and anti-carcinogenic effects on human health, despite lowering the nutritional content of food.\[26,27]\n
**Phytic acid**

Phytic acid act as a storage form of phosphorus that develops in plant seeds like field peas, which is also known as the mixed-cation salt of phytic acid (also called Myo-inositol 1,2,3,4,5,6-hexakis phosphoric acid). Phytic acid accounts for around 60 to 80% of the seed’s total phosphorus. Phytic acid prevents the absorption of divalent cations including calcium, magnesium, zinc, and iron in the gut by chelating these minerals into an insoluble compound that must be expelled. Health-promoting roles for phytic

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**Figure 1.** Advantages and disadvantages of vegetarian diet on sports performance.
acid include diabetes prevention, anti-oxidation, anti-carcinogenicity, and prevention of kidney stones and cardiovascular disease. Phytate’s decrease in nutrient absorption does not negate its health-enhancing properties.\textsuperscript{[28,29]}

**Dietary fiber**

The small intestine is unable to digest dietary fiber, which is a complex mixture of carbohydrates and lignin. There are several ways in which dietary fiber might benefit human health, including lowering cardiovascular disease risk, increasing gut micro-biome diversity, and controlling blood sugar levels. Athletes with high energy needs should be careful not to overeat fiber because it decreases absorption of nutrients and increases feeling full.\textsuperscript{[30,31]} Fiber influences nutrient absorption due to a variety of physicochemical properties, including binding, gel formation, fermentation, viscosity, bulking, solubility, and water holding capacity. In addition, dietary fiber has been shown to slow digestion, boost satiety and reduce caloric consumption. It is beneficial for overall health; it may be best to meet the energy requirements of competitive sports. On the other hand, fibers may be helpful to athletes who want to lose weight.\textsuperscript{[32,33]}

**Protein value**

For the most part, the amino acid profile of a protein source determines how well it can supply essential amino acids (i.e., those that cannot be synthesized by the body or insufficient quantities) to encourage balance in protein synthesis and protein degradation.\textsuperscript{[34,35]} Because VD proteins are “incomplete,” meaning they lack one or more of the nine essential amino acids, they have lesser quality than animal-based proteins. In contrast, animal proteins are deemed “complete,” because they include greater concentrations of all nine essential amino acids.\textsuperscript{[35,36]} Lysine and Threonine are deficient in grains, while methionine, tryptophan, and cystine are deficient in pulses/legumes/beans, and lysine is deficient in nuts and seeds.\textsuperscript{[37]} Tryptophan is also deficient in maize. As a result, people who take a VD must eat a wide array of protein sources to meet their diverse requirements for amino acids.\textsuperscript{[38,39]}

There are also anti-nutritional factors in VD sources such as phytate and fiber that reduce protein digestion.\textsuperscript{[40]} Provide an in-depth look at the impact of anti-nutritional variables on protein digestibility. Regarding the recommended amount of protein for the individual on VD, there is some disagreement in the literature.\textsuperscript{[43]} While some experts recommend that VD individuals must consume 10% extra energy from protein to compensate for the 10% decrease in bioavailability of plant-based sources, others have argued that protein requirements are not reliant on the amount that is consumed.\textsuperscript{[42–44]}

**Sports individual’s nutrition considerations**

Despite the overwhelming evidence that a VD is excellent for overall health and wellness, some continue to raise questions about its suitability for optimizing exercise, particularly regarding concerns of vitamin B12, creatine, iron, and protein. Others, on the other hand, believe that the high levels of carbohydrates, antioxidants, and phytochemicals in a VD make it a better choice for improving athletic performance (Figure 1)

**Energy**

High-fiber, low-energy foods are common in a well-planned, nutritious VD. Thus, a VD is very satiating, resulting in less overall energy use. A VD’s good health consequences in some clinical groups (e.g., diabetes) are typically related to a reduction in total energy consumption, which might be an issue for athletes with high energy requirements. Athletic performance and health can suffer if an
athlete isn’t aware of how much energy he is taking in and how much energy he is expending. VD’s can be used as a disguise for an eating disorder; thus coaches, nutritionists, and mental performance consultants need to be careful of the precise logic for taking a VD and check variations in the athlete’s weight. Athletes should keep an eye on their weight to ensure that they don’t lose too much or too much weight too quickly. It’s recommended that VD athletes eat five to eight meals and snacks per day to get adequate nutrition. They should also reduce their intake of foods high in fiber while increasing their consumption of high-energy foods like nuts and seeds and butter of nuts and seeds as well as dried fruit, trail mix, granola, avocados, and hummus.

**Carbohydrates**

A high mass of carbohydrates and the types of carbohydrates possessed in a VD. VD may help athletes achieve their carbohydrate requirements to achieve their physical activity levels, ensure adequate glycogen concentrations, and prevent early exhaustion, among other benefits. Racewalkers who consumed chronically high carbohydrate diets also had better exercise economy at a given speed than those who consumed low carbs, low fat (i.e., “keto”) diet. Athletes who are engaged in “moderate amounts of strenuous exercise” should take 5–8 g/kg body weight carbohydrates daily to sustain muscle and liver glycogen, as recommended by the international society for sport Nutrition. Regarding endurance and team sports, optimizing muscle glycogen stores may be a way to delay the onset of tiredness in moderate (60–80% VO2max) intensity activity.

Foods having a low glycemic index minimizes the rising glucose in the blood after carbohydrate ingestion is commonly found in healthy VDs. Lipolysis can be encouraged by a decreased insulin concentration, which results from a decreased blood glucose response. It is found that recreational soccer players who ate low glycemic index sports bars, which are manufactured from legumes 2 hours before and at halftime of a simulated soccer game saw an increase in their sport-specific performance and decreased dependence on carbohydrates. Other studies have found no difference in the distance covered at the time of a football match between those who consumed a pulse-based diet for 4 weeks and those who consumed their regular diet (i.e., mixed). Lentils, a low-glycemic index diet, were found to well retain muscle glycogen at the time of simulated football performance than a potato and egg meal that was calorie and macronutrient-matched in terms of calories and macronutrients.

When following a VD, athletes should be careful not to overindulge in the high amounts of fiber that the diet provides. When competing in endurance sports, fiber consumption has been linked to gastrointestinal issues. Protein digestibility may be impacted by high fiber consumption as well. Diets rich in fiber linearly reduces digestibility of protein; however, the specific mechanism through which fiber has an impact on digestibility is unknown.

**Protein**

It’s possible to get all the protein you need from plant-based sources (Table 1), but the amino acid composition in plants is usually less than optimal. Leucine is one of the branched-chain amino acids that can’t be found in plant sources of protein. mTOR, a protein kinase that governs protein production and growth of cells, plays a critical function in muscle protein synthesis through the impact of leucine in stimulating mTOR. Protein quality issues have been substantiated by research that found lower levels of branch chain amino acids in Lacto-ovo vegetarians as well as vegetarians than in their omnivore friends. But according to the Academy of Nutrition and Dietetics 2016 position stand, a varied diet rich in VD protein sources and enough energy are likely to provide adequate intakes of all the essential amino acids needed.

There are conflicting findings in the research on the effects of VD proteins on lean mass and muscle protein production. Others have found that soy protein is inferior to milk protein in terms of
Table 1. Plant-based sources with significant amounts of key nutrients.

| Compounds          | Plant-Based Sources                                                                 |
|--------------------|--------------------------------------------------------------------------------------|
| Protein            | Beans, peas, lentils, chickpeas, soybeans, nuts                                     |
| Omega-3 Fatty Acids | Walnuts, chia, camelina, hemp, flaxseed, soybeans                                 |
| Omega-6 Fatty Acids | Corn, tortilla and potato chips, tofu, tempeh, nuts and seeds, vegetable oils, peanut butter |
| Monounsaturated fatty acids | Canola oil, olive oil, peanut oil, avocado, nuts                              |
| Iron               | Beans, peas, lentils, edamame, chickpeas, nuts, seeds, whole grains, fortified bread and cereals |
| Zinc               | Beans, peas, lentils, chickpeas, edamame, nuts, seeds                               |
| Calcium            | Chinese cabbage, kale, texturized vegetable proteins, tofu, nuts, seeds, beans     |
| Vitamin D          | Fortified cereals, margarine, and plant-based "milk" (almond, soy, oat, pea etc.)  |
| Riboflavin         | Nutritional yeast, quinoa, muesli, fortified cereals and plant-based "milk" (almond, soy, oat, pea, etc.), avocado, wild rice, and mushrooms |
| Vitamin B12        | Nutritional yeast, fortified plant-based "milk" (almond, soy, oat, pea, etc.), fortified meat analogs, shiitake mushrooms |

*Poly unsaturated fat

muscle protein synthesis and lean mass gain following exercise, despite concluding that both are helpful for improvements in strength and lean body mass and that none is superior.

Many studies have shown that for both athletes and non-athletes, a vast diversity of plant-based origins may meet protein needs in developed countries, providing all essential amino acids when calorie intake is appropriate. However, athletes with high-calorie needs may have difficulty getting enough protein from plant-based meals to suit their needs.

People may be concerned about getting adequate protein from whole foods to promote normal muscle protein synthesis because a VD tends to be quite satisfying due to its high fiber content. A protein supplement may be an option for athletes who find it difficult to get enough protein through their diets. Many plant-based protein supplements that have been found to enhance excessive retaliation to exercise and/or exercise performance include pea, mung, hemp, soy, oat, and rice, to guarantee that all essential amino acids are ingested, a plant-based protein supplement prepared with a diversity of protein origins may be superior to supplementing with a single origin. Because of the high concentration of leucine in soy protein, a dietary supplement accommodating this protein may be of special relevance.

Athletes over the age of 30 who are on a VD should keep an eye on their protein intake. Constructive-metabolic resistance is a reduction in the constructive-metabolic response to resistance training and protein intake that occurs through the course of aging. A decrease in amino acid absorption and delivery, as well as altered mTORC1 signaling in reaction to resistance training or protein ingestion, are all common occurrences in older persons. Researchers have discovered that a higher protein intake can compensate for aging’s reduced anabolic response. Study participants who ate a lot of (≥ 1.2 g/kg/day) and high (≥ 1.0 g/kg/day) protein had finer mobility and lower limb function than those who ate a low (< 0.8 g/kg/day), according to observational studies related meta-analysis. This suggests that aged adults may benefit from higher protein intake than younger people. Due to the high satiety of plant-based meals and the lower appetite experienced in older people, these suggested serving sizes may be difficult for older athletes to ingest if they are on a VD. However, older athletes considering a VD should consider three key techniques to improve the anabolic response of VD proteins, as reported by. Supplement with essential amino acids (particularly leucine), combine VD protein sources to achieve good protein quality, and increasing protein consumption to at least 30 g per meal.

Fatty acids

Many of the health benefits of VDs might be linked to the fact that they are lower in fat than a typical Western diet. Although, it is more likely that the type of fat, rather than the amount, is responsible for the positive effects of a VD. Fatty acids (e.g., mono, and polyunsaturated) serve an essential function in
human health, particularly in the prevention and management of certain diseases and inflammatory situations, as well as the absorption of some vitamins. An adequate amount of omega-6 fats (linoleic acid and arachidonic acid) is present in healthy VDs. However, conjugated omega-6 fats (gamma-linoleic acid) are not as prevalent.

Overconsumption of omega-6 fatty acids has been associated with platelet aggregation, inflammation, and vasoconstriction; therefore, moderation is key. When it comes to omega-3 fatty acids, VDs are deficient in the kind found in fatty fish like mackerel and salmon, as well as -linolenic acid (which can be found in VDs like flax) that is found in VDs like walnuts and flaxseed (Table 1). Although eicosapentaenoic acid and docosahexaenoic acid can be synthesized endogenously from alpha-linolenic acid, the process is inefficient and highly dependent on factors such as nutrition, age, gender, and health status. In addition, increased linolenic acid consumption may decrease alphalinalenic acid transformation. Ingestion ratios of 4:1 (linolenic acid to alpha-linolenic acid) is recommended for maximum conversion.

According to previous research by Stupin et al., taking omega-3 fatty acid supplements has been shown to improve injury prevention, energy metabolism, muscle adaptation, and muscle recovery. Athletes who want to maximize their performance should pay close attention to their omega-3 fatty acid intake to make sure they are getting the recommended amounts.

The Omega-3 Index test effectively assesses the levels of EPA and DHA in the blood, more precisely in the membranes of the red blood cells. A cell membrane with 64 fatty acids, of which 3 are EPA and DHA, would get an Omega-3 Index of 4.6%, for instance. An Omega-3 Index test results in a percentage for individuals. So, just what does that mean? The optimal range for Omega-3 Indexes – the lowest risk zone – is 8% or above. However, the majority of consumers are at or below 6%. And regrettably, United States, the majority of individuals are in the zone of severe vulnerability, at 4% or lower. There is a 90% increased chance of abrupt cardiac mortality when one is in the greatest risk area. Numerous health problems, including heart disease, Alzheimer’s, eye disease, and many more, are linked to low omega-3 levels. Athletes who want to maximize their performance should pay close attention to their omega-3 fatty acid intake to make sure they are getting the recommended amounts.

**Micronutrients**

Even though a VD contains acceptable amounts of all micronutrients except B12, it is necessary to pay attention to a few in particular. A licensed dietitian can help you decide whether supplements, such as B12, vitamin D, iron, and calcium, are necessary to prevent or treat nutritional deficiencies. The interested reader is recommended to for further information on micronutrients that frequently need supplementation in athletes.

**Iron**

Erythropoiesis, cell proliferation, energy production, and oxygen transport are all facilitated by iron, which is an essential nutrient in the body. Iron is abundant in a VD (Table 1), but plant-based origins (non-heme iron) have lower bioavailability than animal origins (heme iron). Absorption of non-heme iron needs to be converted from its ferric form (Fe3+) to its ferrous (Fe2+), it may be a less effective and more complicated physiological procedure as compared to the absorption of heme-iron, decreases bioavailability (Figure 2). Additionally, the anti-nutritional factors discussed above may have an impact on bioavailability (Sect. 3). As a result, VD individuals are likely to have lower ferritin levels as compared to omnivores, despite consuming the same or more iron.

More effectively non-heme iron is absorbable in individuals having on vegan diet due to a more adaptable response to long-term VD, hence these individuals are having normal ferritin levels in their body. Aside from ingesting heme origins (maybe not fully on VD) or Non-heme with vitamin C,
various acts can help the body absorb it more effectively, including the avoidance of meals high in calcium, phytates, and polyphenols and physical activity within 2 h of eating.\cite{90}

With more inflammation due to training, more losses of iron through perspiration, and iron losses are at peak due to inhibition in absorbance of iron, blood cells are also destroyed while foot frequently contacting the ground, athletes are more prone to iron insufficiency.\cite{91,92} Due to menstrual iron depletion, women may be at greater risk. Erythropoietin production can also be boosted by increased iron consumption.\cite{93–96} Individuals may supplement iron to boost their performance, mainly in durable sports, due to the higher frequency of deficiency of iron in all populations.\cite{97} This is attributable to a decrease in oxygen-carrying capacity and an increase in the use of anaerobic metabolism in athletes with iron insufficiency, with the level of deterioration positively associated with the level of insufficiency. It’s unclear whether iron supplementation improves performance in people with iron deficiency anemia (low hemoglobin mass due to iron deficiencies). Here methodology to supplementing may play a great part.\cite{98}

In an attempt to sustain homeostasis, individuals with low iron status may develop intestinal modifications that improve absorption while decreasing secretion. Vegetarians and vegans typically do not expect to have deleterious health impacts as a result of lower iron absorption, suggesting that people can adjust to a broad variety of iron status and ingestion. Because of these bioavailability problems, many scientists advised that vegetarians increase their iron consumption by 80%, resulting in adult males and females consuming 14 mg & 33 mg of iron daily (instead of the recommended 8 mg and 18 mg).\cite{87,88} The Institute of Medicine (IOM) agrees and claims that vegetarians need 1.8 times more iron than omnivores do. Furthermore, increased iron intakes for vegetarians and vegans have

\begin{figure}
\centering
\includegraphics[width=\textwidth]{enterocytes-iron-absorption-mechanism.png}
\caption{Enterocytes iron absorption mechanism. Heme–iron carrying protein (HCP), Duodenal cytochrome B (Dcytb) (reducing agent), divalent metal transporter 1 (DMT1), Source: Shaw et al. (2022)
}\end{figure}
been challenged on the premise that they may make people more susceptible to cancer and heart
disease and that more iron may interfere with the absorption of other minerals like copper. Taking
non-heme iron-rich foods along with vitamin C seems to promote non-heme iron absorption, which
might be increased. Many recent researches suggested that contrary to long-standing recommenda-
tions to do so, individuals with iron deficiency anemia (IDA) may not require the addition of vitamin
C to oral iron tablets to assist in absorption.²³

Iron supplementation

Iron supplements aren’t advised until an athlete has been confirmed with IDA and has been properly
evaluated and overseen since they might have unfavorable adverse effects and absorption problems.
Higher dosages (> 50 mg/day), in particular, have been proven to reduce compliance in female athletes
by causing upset stomach and constipation. To prevent insufficiency, athletes are encouraged to devote
greater emphasis to their diets and eat more foods high in iron.⁹¹

It’s crucial to take into account the fact that 18 mg of iron is commonly present in multivitamins.
Given that “free iron” has been linked to oxidative stress throughout exercise, an extra supplement
given to athletes who are not anemic may have negative health impacts (depending on the dosage).⁹⁴
Only groups that are purposefully subjected to hypoxic settings to raise their red blood cell density
might benefit from an iron supplement, others from IDA athletes. Controlling your consumption of
tea, caffeine, and calcium while taking a supplement might help you absorb the iron more effectively.
Athletes should also choose a supplement without calcium salts. Additionally, it has been demon-
strated that lower iron dosages of 39 mg induce less gastrointestinal irritation in female athletes, which
may enhance cooperation. Assisting athletes to increase their dietary iron intake seems to be the clear
and efficient strategy for reducing the proportion of athletes stricken by sports-related anemia. The key
to avoiding iron deficiency encourage athletes particularly women, runners, and vegetarians to look
for dietary counseling & routine iron tests.⁹³

The ferritin concentration in the blood is determined via a blood test. Your cells’ ferritin protein
serves as an iron storage system. Your body can utilize the iron when it is needed thanks to this. The
quantity of iron in your blood is implicitly measured by a ferritin test. The spectrum of acceptable
values is 12 to 300 ng/mL for men and 12 to 150 ng/mL for women. The likelihood that an individual
does not have enough iron increases with the ferritin level, even when it is within the “normal” zone.
If a ferritin test reveals that your blood ferritin concentration is below normal, you possess iron
insufficiency and reduced body iron stores. You could thus be anemic. A ferritin test may reveal
a disorder that leads your body to accumulate too much iron if the results are greater than expected. It
could also be a sign of hyperthyroidism, rheumatoid arthritis, liver illness, or another inflammatory
disorder. Your blood ferritin level may be elevated in conjunction with some cancer types .²⁶–²⁹

Zinc

In trace elements, zinc is the second most common trace element after iron in the body, and it’s critical
to a wide range of metabolic and immunological functions. Zinc insufficiency in modern nations is
extremely unusual; however, plant-based individuals are more prone to decreased plasma zinc levels
than omnivores due to the presence of binding phytates in their diet that is involved in the
malabsorption of zinc.⁹⁹,¹⁰⁰ Individuals with VD have normal zinc levels even though the bioavail-
ability of zinc from VD is reduced. This may be because of due to the mechanism of adaptable
homeostasis which increases the absorption of zinc from Plant-based origins. Anti-nutritional ele-
ments that bind to both zinc and iron can be reduced or even eliminated using some preparatory
techniques in foods e.g. sprouting, soaking, and leavening bread.¹⁰¹

If you’re a competitive athlete, you may need to pay extra observation to the bioavailability of zinc
in your food because of its importance in muscle contraction, immune system function energy
metabolism, and decreased levels of zinc usually seen in physically active populations to inactive
Calcium and vitamin D

Calcium is an important mineral for the human body such as for optimal accumulation of bone minerals, coagulation of blood, the transmission of nerves, muscle contraction, and metabolism. In the human body, it is a more dominating mineral. Some believe that people who don’t consume dairy products aren’t getting enough calcium, but a well-planned VD can supply enough to fulfill the RDA. Many plant-based foods are fortified with calcium to help satisfy dietary guidelines in addition to the numerous VD calcium sources (Table 1). However, excessive quantities of oxalate and, to a lesser extent, phytate reduce the bioavailability of calcium from VD sources. To counteract the lower absorption of calcium VD sources, it has been recommended to consume multiple sources from this type of food group to ensure appropriate absorption.[24]

Aside from its role in inflammation control, bone health, and immunological function, vitamin D also plays a role in muscle function and functions as a hormone that promotes muscle growth.[103–108] Vitamin D deficiency affects 77% of the population in the United States despite the importance of vitamin D in maintaining performance, good health, and well-being.[109–111] Indoor sportsmen who are using extensive sun shielding (e.g., clothing or sun-blocking), living at a high latitude, or having darker skin pigmentation can all put athletes at risk for vitamin D deficiency.[112] If you have darker skin or don’t get enough sun exposure while on a VD, you may be at greater risk of having insufficient levels of vitamin D because of its restricted sources in plant-based foods (Table 1). Endogenous production of vitamin D in the skin is possible for those who receive adequate (but not excessive) sun exposure and use adequate (but not excessive) sun protection.[113] It’s possible to buy commercially available lichen-derived vitamin D supplements if you’re having trouble keeping your vitamin D levels stable and don’t want to use synthetic supplements.[114–117]

Vitamin B complex

We will discuss here only B vitamins such as B₃ and B₁₂ due to their scarcity in the vegetarian diet, even though all B vitamins are critical to performance and good health. As an important energy-metabolizing nutrient, riboflavin (vitamin B₂), takes part in several redox reactions in a variety of metabolic pathways by acting as an electron carrier in its derivatives.[118,119] When it comes to aerobic exercise, deficiency in Riboflavin is likely to have an impact on energy availability because of its role in ATP production.[120] It originates primarily in egg and organ meats, but plant-based foods provide enough to meet the RDA for riboflavin (Table 1). Plant-based foods are often fortified with vitamin B₂ as well e.g., cereal and cereal-based food products. A small amount of extra riboflavin intake is all that is needed to meet the increased needs of those who exercise, and it can be easily obtained through healthy food choices. There is no conclusive evidence that riboflavin supplementation can improve performance even though it plays an important role in numerous metabolic processes. Furthermore, the quality of the research that has been done to date on the topic varies widely.

Homocysteine metabolism and DNA synthesis, as well as red blood cell production and brain signal transmission, may be of special relevance to sportmen. Vitamin B₁₂ (cobalamin) is an essential component, so it is of great interest to athletes. As a result, animal products are the only source of
carnosine, which should be obtained across supplementation. Plant-based “milk” (such as pea, oat, almond, and soy), fortified cereals, and nutritional yeast may offer a small quantity of vitamin B\textsubscript{12}, but this is insufficient. Vitamin B\textsubscript{12} deficiency has been linked to a decrease in creatine biosynthesis, which can harmful for physical performance.\textsuperscript{[121]}

**Creatine**

For high-intensity, short-duration workouts, creatine serves as a fuel source. To sustain creatine storage in an omnivorous diet, it is ingested about 1 g of creatine through fish and meat, and around 1 g of protein is generated endogenously through the metabolism of methionine, arginine, and glycine, which looks to be ample to sustain the level of creatine.\textsuperscript{[122–124]} As a result, the concentrations of creatine in the red blood cells, plasma, serum, and muscle, of VD persons are reduced, but not in the brain.\textsuperscript{[125]} This may lead to less ideal fuel being available for the lactic anaerobic metabolism and, as a result, lowered performance.\textsuperscript{[126]} Those who are taking VD may benefit from using creatine supplements to improve their short-duration, high-intensity workout ability. Because of the “super-compensation” effect, VD persons can boost their creatine levels with creatine supplementation more than omnivores, even though there are no variations in creatine transporters.\textsuperscript{[123,127]}

Even while creatine supplementation has been shown to improve the physical performance of vegetarians, other studies have shown that vegetarians are no better off than omnivores in terms of exercise performance when supplementing with creatine.\textsuperscript{[128]} To match the intake of creatine in the usual omnivorous diet with creatine supplementation of 5 g/day, a daily intake of at least 1 g of creatine supplementation is required. Creatine supplementation may benefit cognitive function and the recovery from concussions, providing additionally fueling for high-intensity exercise, for a short period.\textsuperscript{[129]} Thus, supplementation of creatine may help athletes who play team-based sports.\textsuperscript{[130,131]} It has been advised that vegetarians and vegetarians may benefit more from creatine supplementation for cognition than their omnivore counterparts, however additional research is needed due to methodological problems.\textsuperscript{[129]} When participating in sports with a high risk of concussion, athletes may boost their creatine stockpiles to help them recover faster in the event they suffer.

VD in senior athletes may have lower creatine concentration due to the size of type 2 muscle fibers or a decreased number, of the types, changes in nutritional intake, and the intensity of exercise, compared to younger persons.\textsuperscript{[132]} However, some researchers have found no correlation between aging and creatine concentration in older persons.\textsuperscript{[133]} Recently, a meta-analysis by\textsuperscript{[124]} in which he found that older persons who took creatine with resistance training saw significant gains in lean tissue and strength in both the upper and lower body. It has also been postulated that creatine helps to keep bones healthy and reduces the risk of fractures as we become older. But another meta-analysis by\textsuperscript{[124]} found that there was no remarkable advancement in bones at any of the examined locations (femoral neck, lumbar spine, and the entire body).

**Beta-alanine**

It is an amino acid that is naturally synthesized in the body. Carnosine, an intracellular buffering agent, can only be synthesized at a slow pace from beta-alanine. Those who abstain from eating meat and poultry do not consume beta-alanine, which is found in those foods.\textsuperscript{[134]} Because omnivores consume more beta-alanine than vegetarians, vegetarians have lower muscle carnosine concentrations than omnivores even though beta-alanine can be synthesized endogenously.\textsuperscript{[68,69,135]} As an intracellular buffer, carnosine is critical for exercise performance because it delays exhaustion by protecting the contracting muscles from proton accumulation.\textsuperscript{[136]} This means that lower levels of carnosine could reduce the sports performance. Over the course of 10–12 weeks, 65 mg per kg of beta-alanine supplementation several times per day led to a bit but significant improvement in exercise remains 30–10 minutes.
**Taurine**

Taurine is a neurotransmitter as well as an Osmo-regulator that is found in high concentrations in skeletal muscle, which is an essential amino acid. There are many sources of taurine in the diet, including seafood, meat, and dairy products. People with (VD) may consume very little, resulting in low or inadequate levels. Taurine may have a part in exercise metabolism, found in the muscles of rats after exhausting workout sessions and taurine has lower levels in muscles.\[137,138\] All of the following aspects of exercise performance may be affected by Taurine’s role such as insulin tolerance and glucose tolerance, as well as storage, uptake of the substrate, and oxidation in cardiac and skeletal in skeletal and cardiac muscle. Time trial performance was unaffected by supplementing with 1.66 g of taurine 1 hour before a session of cycling. However, lipid oxidation was increased.\[137\] Research conducted by\[139\] demonstrated that taurine administration for 14 days before and for 7 days after eccentric exercise increased performance while lowering markers of muscle injury and oxidative stress. It is suggested by some researchers that athletes on a plant-based diet should be given 500 mg of taurine supplementation two times a day to boost their performance, although the such type of supplementation is not mentioned in the literature.\[130,139–141\]

**Impact of vegan diet on exercise performance**

In the light of many hypothesis, it has been elaborated that VD may be superior or in some cases inferior to diets containing animal source as meat in enhancing sports performance.\[142,143\] Some of the researchers found VD superior to purely animal-based diet in improving sports performance due to the presence of carbohydrates and some metabolism booster bioactive compounds like polyphenols.\[144\] Polyphenols may lead a VD to be superior for performance than one containing animal products; others have questioned the appropriateness of such eating patterns, with particular concern around protein quality and creatine, particularly when considering muscle protein synthesis\[145\] (Figure 1). The following sections will examine the factors thought to enhance performance as well as the literature on performance outcomes in those following a VD versus omnivorous diet.\[39,123,146–148\]

**Antioxidants and polyphenols**

Being rich in polyphenols and antioxidants that help reduce the degree of oxidative stress and inflammatory response during exercise, a vegan diet can effectively increase endurance sports performance, improves recovery, overall wellness and health in sports individuals. These bioactive compounds beneficial to increase muscle vascularity and improving blood flow, increasing the nutrients and blood supply to working muscles while efficiently disposing of metabolic wastes.\[15\]

It is difficult to draw any radicle conclusion in this regard due to the lack of high-quality research outcomes in this regard.\[149\] In a previous review, antioxidant supplementation in healthy athletes have no effect; however, such type of supplementation improved sports performance in athletes with metabolic deficiencies. Recently some researchers have found that such supplementation even reduces exercise adaptations by reducing biosynthesis in mitochondria, insulin sensitivity and muscular hypertrophy in healthy sports individuals. The research conducted in this area used antioxidant supplements instead of using only whole-natural foods.\[17,149\]

**Effect of vegan diet on body composition**

A growing body of literature has recommended a vegan diet for athletes engaged in weight class or aesthetic sports or any sports type in which weight is directly proportional to sports performance e.g swimming, where a vegan diet helps the athletes in maintaining decreased body mass and lean body type. A correlation between a vegan diet and reduced skinfold thickness and waist-to-hip ratio was
found by Phillpset et al.\textsuperscript{150} independent of weight loss. In another research, it was found that using lentils as post workout meal enhanced fatty acid oxidation due to its low glycemic response as compared to using post-workout diet containing potatoes and eggs. This attribute of lentils in improving fatty acid oxidation may be helpful in leaner body composition. Athletes whose goal is to gain lean body composition along with reduced adiposity can follow a vegetarian diet that is rich in nutrients and low in calorie density. These attributes of a vegan diet can help to maintain ideal body weight due to increased satiety achieved by consuming low caloric intake as compared to consuming calorie-dense foods. Moreover, vegetarian diets also result in decreased gastric emptying rate and weight due to increased satiety achieved by consuming low caloric intake as compared to consuming nutrient absorption, increased satiety and also facilitate fatty acid oxidation.\textsuperscript{39} Athletes whose goal is to improving fatty acid oxidation may be helpful in leaner body composition. Athletes whose goal is to

When considering the increase of lean tissue, the evidence is much more unclear.\textsuperscript{151} In a recent study it has been reported that for gaining muscle mass while following resistance training program no difference was observed between soy and animal protein supplements, while some other studies have recommended milk proteins in gaining lean body mass as compared to soy protein.\textsuperscript{152} A study conducted by Hevia-Larrain et al.\textsuperscript{39} found no difference in achieving power or lean body mass while taking a vegetarian diet along with soy protein isolate supplementation compared to a high protein omnivorous diet along with whey protein supplement. Moreover, some of the studies proposed high protein intake at each meal throughout the day for those following a vegetarian diet. it was further suggested to use specific sources of plant-based proteins for creating an appropriate blend of amino acids from plant-based sources.\textsuperscript{153}

**Effect of vegan diet on sports performance**

There are limited research findings available on the effect of vegan diet on sports performance. The different physiological subsystems play their role in producing exercise performance. Those can be affected either directly, during exercise, through the uptake of specific nutrients but also indirectly, by nutrient-induced modulation of the molecular environment that promotes e.g., muscular adaptations.\textsuperscript{154}

A vegan diet enhances endurance sports performance in a variety of ways by improving blood circulation to muscles, reducing oxidative stress that results in muscle damage, reducing inflammation and improving glycogen storage. The parameters on which endurance sports performance depends are muscle mitochondrial density, muscle vascularity, the concentration of hemoglobin, endothelial function, cardiovascular competence and availability of carbohydrates reserves. The macro and micronutrients present in a vegan diet are more beneficial in improving endurance performance than omnivorous diet. Diet can significantly affect strength performance by different factors like creatine and protein availability that play a key role in muscle mass synthesis. Therefore, inappropriately balanced macro and micronutrient composition of vegan diet may result in compromised strength performance.\textsuperscript{150,155}

There is limited literature available on the effect of vegan diet on muscular adaptability, the currently available literature reports the effect of important nutrients, like leucine, taurine, Docosahexaenoic acid (DHA), Eicosapentaenoic acid (EPA) and short-chain fatty acid (SCFA) on cell signaling in different tissues and can improve sports performance by long term following of different dietary patterns.\textsuperscript{78,156,157} Moreover, dietary choices also affect gut microflora. It has been proved through different studies that diversity in gut microflora can substantially influence pathways like protein synthesis, protein and carbohydrate fermentation, fatty acid oxidation, short chain fatty acid synthesis (SCFA) and inflammation in the intestine. In this way, vegetarian diet has a beneficial role on gut microflora and can improve sports performance by facilitating the aforementioned mechanisms.\textsuperscript{158}

Though, scientific studies are unable to significantly correlate different diets on sports performance. To explore the harmful and useful characteristics of eating habits on exercise performance, upcoming research must prudently use the analysis of cell signaling in combination with physiological data in extended time frames. It is further suggested that upon dietary manipulation different mechanisms
may alter within the body. Therefore, to explore dietary-induced variations in metabolic pathways metabolomics may serve as an important tool.

**Selection of foods for vegetarian diets**

In its most recent position manuscript on vegetarian diets, published in December 2016, the Academy of Nutrition and Dietetics affirmed that well-planned vegetarian diets are appropriate for all phases of life, are wholesome and nutritionally complete, and might be beneficial for the mitigation and therapeutic interventions of chronic illnesses, and are linked to less environmental harm.\textsuperscript{159} Other vegetarian food guides have been created after the 1997 release of the first pyramid-shaped Vegetarian Food Guide (VFG).\textsuperscript{160,161} The Dietary Guidelines for People in Some Western Countries\textsuperscript{162} also provide information and suggestions for vegetarians. Vegetarian diets are becoming more and more well-liked around the globe due to their numerous good impacts.\textsuperscript{163}

It is appropriate for adult vegetarians in Italy & offers nutritional setting up ranging from 1200–3200 kcal. Additionally, it offers modifications specifically for expectant & nursing mothers, including 1,800 to 3,200 kcal in addition to extra portions for the second and third trimesters of pregnancy and breastfeeding. Its goal is to make it simple for vegetarians and health experts to arrange healthy vegetarian diets.\textsuperscript{164} Six dietary groups make up the VegPlate: grains, foods high in protein, fruits and vegetables, nuts and seeds, and lipids. Adults can choose a list of meals from each group that mostly come from the Mediterranean culture to get nutritional data that was typical of each group.\textsuperscript{165} The following foods were used for the estimations: Grains include potatoes, wheat, maize, rice, sorghum, oats, barley, oatmeal, and buckwheat, as well as products made from them (such spaghetti, flatbread, and rice milk). Foods high in protein include beans, peas, legumes, green beans, lentils, soybeans, and products derived from them (tofu, tempeh, and soymilk). Despite being part of the category of foods high in protein, dairy products and eggs were not taken into account when calculations were made. Twenty-five of the most popular vegetable varieties and there are 18 different varieties of fruits that are most popular are being used in Italy. Pistachios, flaxseeds, walnuts, almonds, peanuts, pumpkin seeds, sesame seeds, & hazelnuts are just a few of the nuts and seeds consumers may eat. Due to their distinct nutritional profiles the VegPlate categories nuts and seeds separately from other VFGs. Fats include Flaxseed and olive oils to keep the ideal n-6:n-3 ratio. Additionally, we divided the meals into two additional cross-sectional categories: the group of foods high in calcium includes the foods with the highest calcium content out of all the preceding groups, excluding fats, and the n-3-rich food category includes items from the fats and nuts & seeds groups that are richest in n-3 fatty acids.

**Conclusion**

Vegan diet is rich in nutrition with fewer calories when compared with animal sources that’s why it is gaining the interest of sports individuals striving for leaner body composition along with reduced body weight is the demand of specific sports in which performance is directly related to body weight like swimming, cycling, gymnastic, etc. A carefully designed vegan diet can help to improve sports performance by enhancing recovery and overall wellness in sports individuals on account of a rich source of bioactive compounds with strong antioxidant potential. Moreover, vegetarian diets have proved to improve cardiovascular capacity, muscular vascularity and enhanced blood flow required in endurance sports. This review is an effort to present the latest information extracted from the recently available literature. However, further studies are required to explore this avenue of research as currently limited data is available to approve or disapprove vegetarian diets for enhancing sports performance.
Disclosure statement

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