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Review

Common Nutritional Shortcomings in Vegetarians and Vegans

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Abstract: The popularity of vegetarian and vegan diets is growing due to increased awareness of the environmental and health benefits of such diets. However, despite the consumption of meatless diets being associated with decreased risk of chronic diseases and mortality, followers of these diets are prone to certain nutritional inadequacies, which could limit health benefits. The main nutrients of concern are vitamin B12, vitamin D, iodine, selenium, calcium, and iron. It is essential for all those following vegetarian and vegan diets to implement vitamin B12 supplementation. To prevent vitamin B12 deficiency, adults should take one oral dose of 50–100 μg cyanocobalamin daily or 2000 μg weekly divided into two oral cyanocobalamin doses. Iodine supplementation is essential for pregnant and breastfeeding women and is recommended for vegetarians and vegans who are unable to access sea vegetables or iodine-fortified foods. The recommended dose of iodine supplement for adults is 150 μg daily. Selenium supplementation should be reserved for individuals with clinical evidence of deficiency due to concerns of adverse effects on lipid profiles and type 2 diabetes risk. It is recommended that vegetarian and vegan adults should supplement 4000 International Units (IU)/d of oral vitamin D to prevent deficiency as sunlight exposure is unreliable due to a range of lifestyle and environmental factors. This recommendation also applies to omnivores. As a precaution, those wishing to transition to a more plant-based diet should consider how they will substitute the nutrition they currently obtain from animal-based foods with plant-based sources or appropriate supplementation.

Keywords: plant-based diet; nutrient status; nutritional adequacy

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1. Introduction

The popularity of meatless diets has increased substantially in the past few decades. The prevalence of vegetarians and vegans in Europe, the United States, and Canada is estimated to be between 1–10% [1]. One of the primary drivers of this phenomenon is increased awareness of the impact of diet choices on planetary and human health [2]. It is estimated that transitioning to plant-based diets could reduce diet-related land use by 76%, diet-related greenhouse gas emissions by 49%, and green and blue water use by 21% and 14%, respectively [3]. Vegetarian and vegan diets have been demonstrated to reduce blood pressure, plasma lipids, and body weight, which translates into lower risk of non-communicable diseases, such as cardiovascular disease, type 2 diabetes mellitus, some cancers, and mortality [4–11]. Additionally, the Academy of Nutrition and Dietetics states that appropriately planned vegetarian and vegan diets with reliable sources of vitamin B12, such as fortified foods or supplements, are nutritionally adequate and suitable for all stages of life [12]. However, meat and other animal products are the primary sources of certain micronutrients in omnivorous diets meaning vegetarians and vegans are prone to nutritional inadequacies if their diet is not diligently planned. These may limit or, in cases of deficiency, undermine the chronic disease prevention benefits of vegetarian and vegan diets. The aim of this review is to summarise the key nutrients that vegetarians and vegans are at increased risk of inadequate intake and deficiency compared with omnivores, as observed in epidemiological studies.

2. Vitamin B12

Vitamin B12 (also known as cobalamin) is an essential water-soluble micronutrient that is synthesised exclusively by microorganisms [13]. Vitamin B12 is an essential co-factor required for methylation processes involved in DNA and cell metabolism and it is essential for the production of blood cells and neural tissue [14]. Consequently, vitamin B12 deficiency can lead to a range of serious multi-system clinical manifestations including megaloblastic anaemia and peripheral neuropathy [15]. Primary symptoms of B12 deficiency are unusual fatigue, tingling in fingers or toes, poor cognition, and poor digestion [12]. People with inadequate vitamin B12 intake may present as healthy but over time, subclinical deficiency can lead to stroke, dementia, and poor bone health [12].

Plant-sourced foods are effectively devoid of vitamin B12 due to the removal of B12-synthesising micro-organisms during sanitisation processes [16]. On the other hand, vitamin B12 accumulates in animal produce, such as meat, dairy, and eggs, as livestock require it for health maintenance and are exposed to it via various sources throughout their lives including faeces, feed contaminated with B12-synthesising microbes, feed containing animal-sourced foods, and B12 supplements. It is worth noting that processed meat and red meat are not risk-free sources of B12. Therefore, it is essential that those who follow plant-based dietary patterns that restrict animal products include a reliable source of vitamin B12 in their diets in the form of a B12 supplement and B12-fortified foods. In 2015, The International Agency for Research on Cancer (IARC) classified processed meat as carcinogenic (Group 1) and red meat as probably carcinogenic (Group 2A) due to evidence of a strong association with colorectal cancer [17]. Consumption of red meat was also reported to be positively associated with pancreatic and prostate cancer and processed meat with gastric cancer. This information should be considered by health professionals when recommending sources of vitamin B12 to patients.

In 2021, Bakaloudi et al. [18] performed a systematic review of the nutritional adequacy of vegan diets. Examination of 15 studies totalling 5031 participants revealed that on average, the intake of vitamin B12 was 0–0.9 μg/d in vegans, which is significantly lower than the commonly accepted 2.4 μg/d Reference Nutrient Intake (RNI) [19]. Pawlak et al. [20] conducted a systematic review consisting of 40 studies investigating the prevalence of vitamin B12 deficiency, based on serum vitamin B12, in vegetarians at different stages in life. The deficiency prevalence was 45% for infants, 0–33.3% for children and adolescents, 0–86.5% for adults and elderly individuals, and 17–39% for pregnant women dependent on the trimester. Additionally, the deficiency prevalence in vegans was greater than the prevalence in other vegetarians. It is important to note that the true prevalence of vitamin B12 deficiency in vegetarians is likely higher than reported in this review as serum vitamin B12 is not an accurate marker of vitamin B12 deficiency, i.e., someone can have a normal serum vitamin B12 concentration but be deficient [21]. Pawlack et al. [22] conducted an additional review on the vitamin B12 deficiency rates in vegetarians but this time based on methylmalonic acid (MMA) concentration, holo-transcobalamin II (HTCII) concentration, or both. MMA and HTCII are more effective diagnostic markers than serum vitamin B12 [21]. Data from 18 articles were included in this review. The rates of vitamin B12 deficiency were 62% in pregnant women, 25–86% in children, 21–41% in adolescents, and 11–90% in adults and the elderly. In accordance with the findings of the previous review, higher rates of deficiency were observed in vegans compared with other vegetarians. Greater deficiency rates were also observed in those who were vegetarian since birth compared with those who became vegetarian later in life. High heterogeneity was observed in the deficiency cut-off values employed in the different studies partially explaining the wide range of deficiency rates observed in children and adults. Lower rates of deficiency were reported in studies that used less strict deficiency criteria.

Compared with the consumption of omnivorous diets, vegetarian diets are associated with improvements in traditional cardiovascular disease risk factors such as plasma lipids, blood pressure, and weight status [4–6]. However, this does not always translate into lower cardiovascular disease incidence or mortality [23]. Vitamin B12 deficiency is associated with atherogenic processes that are primarily caused by vitamin B12 deficiency-induced hyperhomocysteinemia. Obersby et al. [24] conducted a meta-analysis investigating total serum homocysteine (Hcy) concentration among vegetarians in comparison with omnivores. A total of 17 studies with 3230 participants were included in the analysis. The mean (SD) Hcy concentration in vegetarians was 13.91 (3.5) µmol/L and in vegans was 16.41 (4.8) µmol/L. In contrast, the mean Hcy concentration in omnivores was only 11.3 (2.89) µmol/L. Hyperhomocysteinemia was assessed in 20 of the included samples. Of the 20 the prevalence of hyperhomocysteinemia in vegetarians was greater than 50% in 13 of the samples. Each 5 µmol/L increase above 10 µmol/L of serum homocysteine is associated with a 20% increased risk of circulatory health problems [23]. Therefore, the cardiovascular disease prevention benefits associated with the consumption of vegetarian diets may be undermined by vitamin B12 deficiency.

Eggs and dairy products cannot sufficiently meet the vitamin B12 RNI when part of a balanced vegetarian diet due to losses in vitamin B12 content and bioavailability during cooking [21]. For this reason, it is the position of health associations that vitamin B12 supplementation is required for those following any forms of a vegetarian diet [12,25]. It was widely believed that vitamin B12 deficiency took decades to develop but emerging evidence has shown that it can develop in just 2 years after commencing a vegetarian diet [26,27]. Vitamin B12 supplementation should therefore start with the commencement of vegetarian and vegan diets.

Although it is possible to obtain adequate vitamin B12 from fortified foods, such as nutritional yeast and plant-based alternatives, the need for multiple daily servings makes attaining vitamin B12 from these sources impractical and hence leads to poor adherence [21]. Furthermore, it has been demonstrated that vitamin B12 supplementation is more effective at rectifying deficiency than the implementation of nutritional yeast [26]. In a cross-sectional analysis of the Third National Health and Nutrition Examination Survey (NHANES III), the reported use of vitamin B12-containing supplements was associated with at least 50% lower prevalence of both low serum vitamin B12 concentration and biochemical vitamin B12 deficiency [28]. In a 2023 systematic review, Bärebring et al. highlight that no conclusions can be drawn on whether habitual B12 intake or an intake in line with guidelines is sufficient to prevent deficiency in vegetarians and vegans due to an absence of prospective cohort studies relating B12 intake to status among vegetarians or vegans [29].

Multiple forms of vitamin B12 supplement are available including cyanocobalamin, methylcobalamin, adenosylcobalamin, and hydroxycobalamin [30]. Cyanocobalamin is the most recommended form due to its high stability, cost effectiveness, and safety profile [31]. The absorption of oral vitamin B12 supplements is dependent on dosage and frequency of intake [32]. In general, higher dosages have worse absorption efficiencies [21]. Oral administration of cyanocobalamin has been demonstrated to be as effective as intramuscular administration in the treatment of vitamin B12 deficiency [33]. There is no universal cobalamin dosing recommendation for health maintenance in those following vegetarian diets [34]. Additionally, the tolerable upper intake of vitamin B12 has not been defined due to insufficient data on toxicity events [21]. Since vitamin B12 is water soluble and necessitates a specific transport system which is easily saturated, its accumulation and excess absorption are improbable [35]. To meet the daily requirement of vitamin B12 it has been suggested that vegetarian adults should take one oral dose of 50–100 µg cyanocobalamin daily or 2000 µg weekly divided into two oral cyanocobalamin doses [21].

3. Vitamin D

One of the main roles of vitamin D in the human body is to maintain healthy serum calcium and phosphorus concentrations, which in turn supports a variety of metabolic functions, transcription regulation, and bone metabolism [36]. The known biological influence of vitamin D has expanded significantly over the past several decades. It is now known that vitamin D metabolites can initiate physiologic responses in more than 36 cell types [37]. Therefore, the influence of vitamin D has the potential to span multiple systems offering a broad role in health maintenance. Vitamin D insufficiency and deficiency have been linked to a plethora of undesirable health outcomes including rickets, osteomalacia, certain types of cancers, cardiovascular disease, type 2 diabetes mellitus, autoimmune diseases, neurologic disorders, adverse pregnancy outcomes, and mortality [36].

Vitamin D is unique in that it is not technically a vitamin, i.e., an essential factor that must be obtained via diet. Vitamin D is synthesised endogenously in the skin through the action of sunlight and is increasingly recognised as a prohormone rather than a vitamin [36,37]. Therefore, provided an individual has access to adequate sunlight exposure, there is no need for dietary intake of vitamin D. However, there are concerns about the safety of this source as extensive ultraviolet radiation exposure is associated with increased risk of skin cancer and melanoma [38]. There are also various accessibility barriers that prevent subgroups of the global population from being able to obtain adequate sunlight. Factors that impact an individual's ability to produce adequate vitamin D from sunlight include skin pigmentation, sunscreen use, time of day of exposure, season, latitude, altitude, and air pollution [36]. It is estimated that, on average, 20% of vitamin D is acquired from dietary intake and 80% from sun exposure [39]. Vitamin D does not naturally occur in plant-sourced foods. The richest natural sources of vitamin D are fish, egg yolk, and offal such as liver [40]. Vitamin D can also be sourced from fortified foods, which commonly include dairy products, fat spreads, fruit juices, breakfast cereals, and plant-based milk alternatives [41]. An additional significant food source of vitamin D is UV-irradiated mushrooms [40]. Considering most sources of vitamin D are of animal origin, one can see how challenging obtaining sufficient vitamin D from food would be whilst following a vegetarian diet.

A small body of evidence indicates that those following vegetarian diets have inadequate dietary intake of vitamin D and higher rates of vitamin D insufficiency and deficiency than omnivores. In a systematic review of the nutrient intake of vegans, Bakaloudi et al. [18] found that vegan diets were associated with a lower intake of vitamin D compared with omnivorous and other vegetarian diets or lower intake than the reference intake value (based on 11 studies with a total of 4703 participants). Crowe et al. [42] performed a cross-sectional analysis of the European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford cohort to determine the extent to which the low vitamin D intake observed in vegetarians impacts plasma 25-hydroxyvitamin D concentrations. The results from a total of 2017 British participants showed that plasma 25-hydroxyvitamin D concentrations reflected the degree of animal-based food exclusion (meat eaters > fish eaters > vegetarians > vegans). Meat eaters had the highest mean plasma 25-hydroxyvitamin D concentration (77.0 [95% CI 75.4, 78.8] nmol/L) and vegans had the lowest (55.8 [95% CI 51.0, 61.0] nmol/L). The plasma 25-hydroxyvitamin D concentrations of meat eaters remained superior to that of vegetarians and vegans when sampled in the summer months, highlighting the importance of dietary intake of vitamin D even when sunlight is available. Plasma 25-hydroxyvitamin D concentrations below 25 nmol/L are considered to increase the risk of bone-related diseases [43]. The prevalence of concentrations below this threshold in the winter and spring months was <1% for meat eaters, 3% for both vegetarians and pescatarians, and 8% in vegans.

In accordance with the previous study's findings, Ho-Pham et al. [44] found that omnivores had significantly higher plasma 25-hydroxyvitamin D concentrations than vegans in a cross-sectional analysis of 210 postmenopausal Asian women (105 omnivores and 105 vegans). Using plasma 25-hydroxyvitamin D concentrations <30 ng/mL and <20 ng/mL as the cut-off values for vitamin D insufficiency and deficiency, respectively, the prevalence of vitamin D insufficiency was 73% in vegans and 46% in omnivores and the prevalence of vitamin D deficiency was 27% in vegans and 6.5% in omnivores [45]. Also in agreement with the aforementioned findings, Hansen et al. [46] found that vegans had significantly lower plasma 25-hydroxyvitamin D concentrations than omnivores in a cross-sectional analysis of 155 Danish participants (78 vegans and 77 omnivores). Additionally, vegans were 4 times more likely to be vitamin D insufficient and 16 times more likely to be deficient than omnivores.

The high rates of vitamin D insufficiency and deficiency observed in vegetarians relative to meat eaters may partially explain why the consumption of vegetarian and vegan diets are often associated with poor bone health. In a 2019 meta-analysis including 20 studies and 37,134 participants, vegetarians and vegans had lower bone mineral density at the femoral neck and lumbar spine than omnivores [47]. Vegans also had higher fracture risk when compared with omnivores. In 2020, the total and site-specific fracture risks of vegetarians and vegans in the EPIC-Oxford prospective cohort were published [48]. The study followed 54,898 participants over an average of 17.6 years of follow-up. After adjustment for confounders, vegetarians and vegans had higher risks of hip fracture compared with meat eaters. Compared with meat eaters, vegans also had higher risks of total, leg, and other main site fractures. Interestingly, the higher fracture risks observed in vegans were attenuated after adjustments for BMI and dietary calcium and protein intake but remained significant, suggesting that these factors only partly explain the increased risk. Differences in vitamin D levels between vegans and meat eaters may play a role in the increased fracture risks of vegans; however, more research is required to confirm this.

There are many lifestyle and environmental factors, for example, the use of anti-UV filter creams, skin colour, latitude, obesity, and age, that make sunlight exposure an unreliable source of vitamin D, so the prevention of insufficiency and deficiency in those following vegetarian and vegan diets is best achieved by implementing a vitamin D supplement of an appropriate dose [49]. According to the Endocrine Society's clinical practice guidelines, oral doses up to 1000 IU/d for infants up to 6 months, 1500 IU/d for infants from 6 months to 1 year, 2500 IU/d for children aged 1–3 years, 3000 IU/d for children aged 4–8 years, and 4000 IU/d for everyone over 8 years can be administered safely without medical supervision to prevent vitamin D deficiency [50]. This recommendation applies to both vegetarians and omnivores. Vitamin D supplements are available in two forms: vitamin D2 and vitamin D3. Randomised controlled trials have demonstrated that vitamin D3 is more proficient at increasing plasma 25-hydroxyvitamin D concentrations than vitamin D2 [51]. Therefore, the preferred supplement form for those following vegetarian diets is vitamin D3.

4. Iodine

Iodine is an essential micronutrient necessary for the synthesis of thyroid hormones. Triiodothyronine (T3) and thyroxine (T4) consist of two coupled tyrosine molecules to which three (T3) or four (T4) iodine atoms are bound [52]. Thyroid hormones have important roles in the regulation of metabolism, growth, and neurological development [53]. Iodine deficiency is associated with multiple adverse health effects, which are collectively termed iodine deficiency disorders (IDDs). These include hypothyroidism, goitre and its complications, endemic cretinism, and impaired mental function [54]. The natural iodine content of most foods is low. The main sources of iodine in the typical Western diet are iodised salt, dairy products, and bread [55]. The native iodine content of dairy products is increased by the use of iodine-based cleansers to sanitise udders, which leach into milk and iodine-enriched cattle feed [56]. Similarly, the iodine content of bread is enhanced by the use of iodine-containing dough conditioners, such as iodate and iodised salt [54]. Overall, 250 mL of cow's milk contains approximately 110 μg of iodine, providing a substantial contribution towards the Institute of Medicine's daily iodine intake recommendation for adults (150 μg/d) [57]. Plant-based milk alternatives fortified with iodine provide a similar concentration of iodine as cow's milk; however, an analysis of 47 plant-based milk alternative products sold in the UK revealed that only 6.4% were fortified with iodine [58]. The median iodine concentration of all the unfortified plant-based milk alternatives included in this study was only 1.7% of that of conventional cow's milk. Therefore, individuals replacing cow's milk with unfortified plant-based milk alternatives are at risk of under consuming iodine and must find alternative dietary sources of iodine. Generally, foods of marine origin have higher iodine content as marine organisms accumulate iodine from seawater. Sea vegetables are a rich plant-based source of iodine but they have poor cultural acceptability in Western countries. Just 10 g of Nori seaweed is sufficient to meet the 150 μg/d iodine recommendation [59]. Land-sourced plant-based foods are not reliable sources of iodine as the iodine content of the soil is often depleted and has large variability [60].

A 2021 systematic review consisting of eight studies and a total of 1890 participants found that the intake of iodine among vegans was significantly lower than that of non-vegans and frequently lower than the 150 μg/d RNI [18]. In 2020, a systematic review of studies assessing the iodine intake and status of adults following vegetarian and vegan diets was published [53]. Data from 15 articles and a total of 127,094 participants were considered. The study found that those following a vegan diet tended to have the lowest intake of iodine, whereas omnivores were reported to have the greatest intake in 83% of studies. Those following a vegan diet also presented the lowest median urinary iodine concentrations and did not attain optimal status. Those following vegetarian diets had higher median urinary iodine concentrations compared with vegans but were inferior when compared with omnivores. Mild to severe iodine deficiency was recorded in vegans in six studies, vegetarians in two studies, and omnivores in four studies. Interestingly, one of the included studies found that vegans had excessive iodine status due to the overconsumption of high iodine-content seaweed.

Case studies have been published linking the consumption of vegan diets to iodine-deficient hypothyroidism and goitre formation [61,62]. However, in the only prospective cohort study published investigating the risk of hypothyroidism in vegetarians and vegans, following a vegan diet tended to be protective [63]. In an analysis of the prevalence of hypothyroidism (N = 65,981), prevalent cases were associated with a lacto-ovo vegetarian diet whilst a vegan diet was associated with decreased risk (not statistically significant). In an analysis of the incidence of hypothyroidism (N = 40,910), vegan diets were associated with reduced risk (not statistically significant) and lacto-ovo vegetarian diets were associated with increased risk compared with omnivorous diets. Differences in iodine intake and status between the diet groups were not recorded so their influence on the results is unknown. In an attempt to explain these unforeseen results, the authors hypothesised that animal products may cause an inflammatory milieu that promotes autoimmunity. If accurate, iodine deficiency may undermine and limit the potential hypothyroidism prevention benefits of vegan diets. Research on pregnancy outcomes in relation to vegan and vegetarian diets is scarce. In a systematic review including 22 studies and 13 maternal-foetal outcomes, none of the studies reported an increased risk of severe adverse outcomes in those following vegetarian or vegan diets and only one study reported an increased risk of major malformation in the form of hypospadias [64]. The authors concluded that vegetarian and vegan diets may be considered safe in pregnancy so long as vitamin and trace element requirements are met.

The most convenient sources for vegans to achieve their iodine requirements are iodised salt, plant-based milk alternatives fortified with iodine, sea vegetables, and iodine supplements. Individuals choosing sea vegetables should be cautious of excess iodine intake which can lead to hyperthyroidism [65]. In cases where iodised salt and fortified plant-based milk alternatives are not available and regular sea vegetable consumption is not possible, an iodine supplement should be taken. Health organisations such as the American Thyroid Association and the American Academy of Paediatrics recommend that women who are planning pregnancy, are pregnant, or are breastfeeding should take a daily supplement containing 150 μg of iodine regardless of their diet [66]. This recommendation should be extended to vegans and vegetarians with inadequate iodine intake.

5. Selenium

Selenium is a trace element essential for a range of biological functions in humans. The primary effects of selenium are expressed when it is incorporated into the catalytic centre of selenoproteins. In total, 25 selenoproteins have been identified and their expression has been observed in a wide range of tissues [67]. Selenoproteins have an array of functions including free radical neutralisation, calcium flux control, and maintenance of thyroid hormone concentration [68]. Selenium deficiency has been linked with cardiovascular disease, myodegenerative diseases, cancer, and cognitive decline [69]. Humans mainly obtain selenium through the ingestion of selenoamino acids (selenomethionine, selenocysteine, and selenocystine). The selenium existent in plant-based foods, such as cereals and vegetables, has a higher bioavailability (85–100%) compared with that observed in dairy products and meats (10–15%) [70]. However, the selenium content of plant-based foods is highly variable as it is dependent on the selenium concentration of soil [69]. Due to this and the fact that farm animals are generally supplemented with selenium, animal-derived foods and seafood generally have higher selenium content than plant-based foods [71]. In regions with poor soil selenium concentrations, such as Central and Northern Europe, meat and fish are often the main sources of selenium in omnivorous diets [72,73]. In regions with adequate soil selenium content, brazil nuts, seeds, green vegetables, shiitake mushrooms, and button mushrooms are rich sources of selenium [74]. Those following vegetarian diets in regions with low soil selenium content may struggle to reach their selenium requirements.

Bakaloudi et al. found five studies with a total of 1737 participants that examined the selenium intake of vegans [18]. Overall, these studies suggested that vegans were more likely to have low selenium intake than non-vegans. In accordance, a cross-sectional analysis of 62 women from the UK found that vegans had significantly lower intakes of selenium than both vegetarians and omnivores [75]. The main sources of selenium in the omnivores were meat, eggs, fish, and dairy. An additional cross-sectional study of 430 children aged 1–3 years living in Germany found that those following a vegan diet had a significantly lower median daily selenium intake compared with those following omnivorous diets [76]. This study also showed that 39% of vegetarians, 36% of vegans, and 16% of omnivores fell below the adequate intake threshold for selenium (15 μg/d for children). In a cross-sectional analysis of the EPIC-Oxford cohort consisting of 30,251 participants, vegetarians reported a significantly lower mean intake of selenium than meat eaters and fish eaters [77]. Vegetarians and vegans also had a higher prevalence of inadequate selenium intake than meat eaters and fish eaters. Multiple studies have shown that vegetarians and vegans in regions of low soil selenium content have lower selenium statuses than their omnivorous counterparts [71,78–81].

Despite having increased fibre intake and zero intake of red and processed meats, vegetarians and vegans living in the UK do not appear to have lower colorectal cancer risk than omnivores [82,83]. This is conflicted by observations of reduced colorectal cancer risk in those following vegetarian diets in the USA when compared with omnivores [84,85]. Since the most pronounced difference in nutritional status between British and American vegetarians is selenium status, researchers have hypothesised that low selenium intake and status modifies the impact of vegetarian diets on colorectal cancer risk [86]. More research is needed to characterise this potential effect modification.

In summary, the literature on the topic of plant-based diets and selenium is scarce but the current body of evidence suggests that those following vegetarian diets in low selenium regions are at high risk of inadequate intake. Some researchers have recommended that this risk group of the population should supplement their diets with selenium [78]. However, selenium supplementation has been associated with adverse lipid profiles and increased risk of developing type 2 diabetes, so supplementation should be reserved for those with evidence of deficiency [87–89]. Other researchers have suggested that those following plant-based diets in poor soil selenium regions should implement an adequate country-of-origin-dependant dosing of Brazil nuts [86].

6. Calcium

Calcium is the most abundant mineral in the human body accounting for approximately 2% of an average adult's bodyweight [90]. Only 1% of total calcium is found in body fluids and soft tissues, the remainder is stored in bones and teeth [90]. Calcium is essential for bone growth and attaining peak bone mass. Insufficient calcium intake can lead to low bone mineral density, which may increase the risk of osteoporosis in later life [91]. Calcium is found in a wide variety of foods but the amount of calcium and its bioavailability vary significantly. A major source of dietary calcium is dairy products such as milk, yoghurt, and cheese. It is estimated that dairy products provide more than 40% of the calcium intake amongst British adults [90]. Therefore, those following vegan diets may be at risk of falling short on calcium intake. Bakaloudi et al. identified 14 studies with a total of 6376 participants that investigated diet choice and calcium intake [18]. Together, these studies showed that vegans had lower calcium intake than non-vegans. Additionally, 76% of those following vegan diets did not meet the WHO calcium RNI. A 2022 meta-analysis including 74 studies and a total of 166,877 participants found that vegans had substantially lower calcium intake than both vegetarians and omnivores [92]. Additionally, there was no statistically significant difference between the calcium intakes of vegetarians and omnivores. In a cross-sectional study of 78 vegans and 77 omnivores, vegans had higher concentrations of circulating bone turnover markers compared to omnivores [46]. The authors concluded that this was likely in part due to lower intake of calcium and vitamin D in the vegans. In a meta-analysis of 20 studies with a total of 37,134 participants, vegans had lower bone mineral density at the femoral neck and lumbar spine and higher fracture rates than omnivores [47]. More research is needed to resolve the causes of this phenomenon but low calcium intake combined with low vitamin D status are likely contributors.

Consequently, vegans should focus on including calcium-rich foods with high bioavailability in their diets. Due to the presence of absorption-inhibiting compounds such as phytic acid and oxalic acid, the bioavailability of calcium in plant-based foods is highly variable. Although many green leafy vegetables have high calcium content, they can also be rich in oxalic acid (e.g., spinach and Chinese spinach), which reduces the calcium bioavailability to about 5% [90]. On the other hand, green leafy vegetables with low oxalic acid concentrations such as kale, Bok choy, and Chinese mustard greens, boast calcium bioavailability values between 40–50%. Legumes and beans often have high phytic acid concentrations, which generally reduces the bioavailability of calcium to approximately 20% [93]. Soya beans and products are an exception as they have high concentrations of phytic acid and oxalic acid yet the calcium they contain is 30–40% bioavailable [94]. Tofu is a particularly rich source of calcium as calcium is often added as a coagulant [90]. Plant-based milk alternatives are routinely fortified with calcium, which is estimated to be 75% as bioavailable as the calcium in cow's milk [95]. Vegans with low calcium status should try to address the issue by increasing their intake of calcium-fortified foods and other calcium-rich plant-based foods before they consider supplementation as calcium supplements have been associated with an increased risk of cardiovascular events [96].

7. Iron

Iron is an essential micronutrient necessary for the production of haemoglobin and myoglobin. It is also crucial for numerous physiological and cellular processes such as DNA synthesis and electron transport [97]. Iron deficiency can be asymptomatic or cause a diverse portfolio of symptoms. Common symptoms include fatigue, dizziness, pallor, headache, alopecia, and restless leg syndrome [98]. These symptoms may be a result of iron deficiency anaemia; however, they can still present in the absence of anaemia. Severe cases of iron deficiency can lead to haemodynamic instability. Numerous plant-based foods have high iron content, such as legumes, whole grains, and dark-green leafy vegetables [99]. As a result, it is viable for vegetarian diets to have similar iron content to omnivorous diets including meat. Interestingly, higher iron intake has been observed in vegetarian and vegan samples compared with omnivores in multiple cohort studies [100–102]. However, a meta-analysis of 24 cross-sectional studies examining the iron status of vegetarians found that vegetarians and semi-vegetarians had significantly lower serum ferritin levels compared with non-vegetarians [103]. Additional studies have reported a higher prevalence of iron deficiency and iron deficiency anaemia in vegetarians compared with meat eaters [104–106]. Despite having a similar or higher intake of iron compared with meat-eaters, those following vegetarian diets have lower iron stores because the iron found in plant-based foods is less bioavailable and therefore absorbed less than the iron present in meat [107].

There are two types of dietary iron: haem and non-haem iron. Approximately 40% of the total iron present in meat is haem iron and the remainder is non-haem iron. Haem iron only makes up 10–15% of total iron intake in omnivores but due to its superior absorption, it is estimated to contribute at least 40% of total iron absorbed [108]. Plant-based foods on the other hand only contain non-haem iron. The mean iron absorption from a vegetarian diet is reported to be 10%, whereas the mean absorption is 18% for meat-containing diets [109]. The absorption of non-haem iron is negatively influenced by the presence of inhibiting factors, such as phytic acid and polyphenols, in plant-based foods [110]. The leavening of bread and the soaking and sprouting of legumes, whole grains, and seeds have been shown to reduce phytic acid levels [111]. The absorption of non-haem iron is increased when combined with enhancer compounds such as vitamin C and vitamin A. Vitamin C is the most potent enhancer of iron absorption and can overcome the inhibitory effects of phytic acid and other inhibitors [110]. Therefore, those following vegetarian diets should consider combining their meals with a source of vitamin C to maximise iron absorption. Additionally, vegetarians should consider restricting their coffee and tea consumption to the outside of main meal windows as they have been demonstrated to inhibit iron absorption [112].

Although those following plant-based diets may be at increased risk of iron deficiency and iron deficiency anaemia, it is worth noting that high iron stores have been associated with increased risk of certain non-communicable diseases for example, type 2 diabetes mellitus and metabolic syndrome [113,114]. Since the absorption of haem iron is unregulated, eating less meat and more plants is a good option for individuals with high iron stores [110]. Some researchers have suggested that the non-communicable disease prevention benefits of plant-based diets may partly be mediated by the low bioavailability of iron [115].

8. Discussion

This narrative review highlights vitamin B12, vitamin D, iodine, calcium, selenium, and iron as nutrients of concern for vegetarians and vegans. Epidemiological studies consistently show that vegetarians and vegans are at higher risk of deficiency and inadequate intake of these nutrients compared with omnivores. This information is vital in the context of current global shifts to plant-based dietary patterns for environmental sustainability. It is estimated that a 50% reduction in meat and dairy consumption is required by 2050 to reduce livestock-related greenhouse gas emissions below 2020 levels, assuming there is no change from current production practices [116]. Therefore, it is necessary to plan how the nutrition currently provided by animal-sourced foods will be adequately replaced. This will likely entail multisectoral actions and a full range of policy interventions, for example, food fortification programmes.

Such dietary shifts would garner a plethora of health co-benefits. Meta-analyses of interventional trials have shown that vegetarian and vegan diets significantly improve cardiometabolic risk factors, including blood pressure, plasma lipids, bodyweight, and haemoglobin A1c levels [4–7]. In a 2021 meta-analysis, we showed that plant-based diets containing some animal products, for example, the healthy Nordic diet and DASH diet, display the same blood pressure-lowering benefits as stricter vegetarian diets [4]. These diets may be a more realistic and achievable goal than vegetarian diets for those trying to reduce their environmental impact. More research is needed to determine whether individuals following these less restrictive plant-based diets are at risk of the same nutrient inadequacies as vegetarians and vegans.

It is essential that we continue to monitor the nutritional profiles of vegetarians and vegans, particularly as the composition of their diets changes and evolves. Between 2018 and 2020, the consumption of plant-based meat alternatives in the European Union increased by 49% [117]. It is predicted that meat and dairy alternatives could make up as much as half the global market for animal proteins by 2050 [118]. Therefore, it is imperative that we monitor the impacts of replacing current foods in the diet with these novel animal product alternatives on the intake of important nutrients. A cross-sectional survey of 207 plant-based meat alternatives available in the UK showed significantly lower energy density, total fat, saturated fat, protein, and significantly higher fibre compared with their animal-sourced counterparts [119]. However, salt was significantly higher in the plant-based meat alternatives. This is concerning as it is likely to undermine the blood pressure-lowering benefits of plant-based diets. This is supported by our meta-analysis of controlled trials that showed no significant changes in blood pressure when animal-sourced meat was replaced with plant-based and mycoprotein-based meat alternatives [120]. More research is needed to determine the differences in micronutrient profiles between animal-sourced meats and plant-based meat alternatives.

8.1. Guidance for Prospective Vegetarians and Vegans

When transitioning to a vegetarian or vegan diet, it is essential to have a regular source of vitamin B12. For most people, taking a vitamin B12 supplement is the most reliable and convenient source. To meet the daily requirement, adults should take one oral dose of 50–100 µg cyanocobalamin daily or 2000 µg weekly divided into two oral cyanocobalamin doses [21]. Additionally, it is not a bad idea to start vitamin D supplementation, particularly for those living in northern latitudes or with dark skin colour. Those who are obese, elderly, or spend a lot of time indoors should also take a vitamin D supplement. Adults should take 4000 International Units (IU)/d of oral vitamin D to prevent deficiency [50]. To prevent calcium deficiency, vegans should make sure their diets are rich in low oxalate leafy greens, such as kale, Bok choy, and Chinese mustard greens, soya products including tofu, and calcium-fortified plant-based milk alternatives. To prevent iron deficiency, vegans should include a range of legumes, whole grains, and dark-green leafy vegetables in their daily diets. These foods can be combined with vitamin C-rich foods, such as bell peppers, broccoli, Brussels sprouts, kale, citrus fruits, kiwi, and strawberries, to enhance the absorption of iron [110]. Tea and coffee should be avoided around mealtimes as they inhibit iron absorption [112]. To prevent iodine deficiency, vegans should incorporate iodine-fortified plant-based milk alternatives or sea vegetables into their daily diets. The number of servings of sea vegetables should be limited to prevent excess iodine intake. Alternatively, a daily supplement containing 150 µg of iodine could be implemented [66]. To prevent selenium deficiency, vegans that live in poor soil selenium regions such as central and northern Europe should implement a daily serving of Brazil nuts. Selenium supplementation is not recommended unless clinical evidence of deficiency is present due to the risk of adverse cardiometabolic outcomes.

8.2. Limitations

This study has some limitations. Firstly, it followed a narrative review methodology so it is possible that some relevant sources may have been missed that otherwise would not have if following a more systematic approach. Secondly, we were unable to investigate the nutritional adequacy of other less strict plant-based diets. A plant-based diet is an umbrella term that describes any dietary pattern that emphasises the consumption of foods derived from plants and excludes or limits the consumption of most or all animal products. These dietary patterns have been shown to produce some of the same benefits as vegetarian diets whilst being less restrictive [4]. More research is warranted to determine whether more flexitarian approaches are prone to the same nutritional shortcomings as vegan and vegetarian diets.

9. Conclusions

Vegetarian and vegan diets are associated with a collection of nutritional inadequacies, which may limit the classical non-communicable disease prevention benefits of these dietary patterns. Therefore, these diets require meticulous planning to ensure they are nutritionally complete. The inclusion of foods fortified with vitamins and minerals is a useful tool but they are not accessible to all populations so vegetarians and vegans should implement a suitable supplement regime. It is imperative that we continue to monitor the nutrient profiles of such diets, particularly as novel meat and dairy alternatives become more popular.

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