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Nutritional Considerations of Plant-Based Diets for People With Food Allergy

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ABSTRACT

Plant-based diets (PBD) have been reported throughout history, but are increasingly common in current times, likely in part due to considerable emphasis on climate change and human health and wellness. Many dietary organisations around the world endorse well-planned, nutritionally adequate PBD, which exclude some or all forms of animal-based foods. However, special attention must be given to patients who follow PBD and also have food allergy (FA), as avoidance may increase the risk of developing nutritional deficiencies, including poor growth in children, weight loss in adults and vitamin and mineral deficiencies. Given the increasing prevalence of both PBD and food allergen avoidance diets, healthcare providers are likely to counsel patients with FA who also follow a PBD. In this review, an overview of PBD in patients with FA is provided, including recent trends, macro- and micronutrient needs, and growth for children and weight gain considerations for adults. With regard to a PBD, special attention should be given to ensure adequate fat and protein intake and improving the bioavailability of several minerals such as iron, zinc, iodine, calcium and magnesium, and vitamins such as A, B2, B12 and D. Although the collective data on growth amongst children following a PBD are varied in outcome and may be influenced in part by the type of PBD, growth must be regularly monitored and in adults weight gain assessed as part of any clinical assessment in those people with FA.

In some cultures and countries, versions of plant-based diets (PBD) have been practised for centuries [1]. Recently, PBD have received near-global visibility in scientific and mainstream literature [1]. This shift is multi-etiologic, ranging from concerns about human health and animal welfare [1]; to efforts of reducing carbon footprints in the wake of climate change [2, 3]; and for ethical and/or religious reasons [4]. Although many dietetic and governmental organisations endorse well-planned PBD [5–8], these diets may increase the risks of nutritional deficiencies [9, 10], which may be alleviated through supplementation [10]. A nutritionally adequate PBD may be challenging when co-occurring with dietary eliminations for medical management, including those associated with Immunoglobulin E (IgE) or non-IgE mediated food allergy (FA) [11, 12].

Summary

- Food allergy (FA) and plant-based diets (PBD) involve dietary restrictions, which may increase risks for nutritional deficiencies.
- FA and PBD may coexist, which may create more challenges during nutritional counselling.
- Counselling should include emphasis on both macronutrients and micronutrients, and growth should be monitored.

FA affects ~7%–8% of children [13–15] and adults [13–16] in parts of the world for which prevalence data are available. Although FA typically first presents in infancy [17], the rates of adult-onset FA are also increasing [16]. FA is typically managed by avoiding known allergen(s), tailored to the individual's need, including consideration of tolerance of baked milk and egg and how to manage precautionary allergen labelling [17]. Given the increasing commonality of both PBD and FA, it behoves healthcare professionals to understand the unique dietary needs of this population. We aimed to provide an overview of PBD, including recent trends, macro- and micronutrient needs, and growth considerations for those with FA.

1 | Overview and Epidemiology of Plant-Based Diets

Traditionally, individuals who avoided meat consumption were termed vegetarians, and those who avoided animal products in all forms were called vegan. Although these terms persist in common vernacular, they are inadequately descriptive in the context of present day. Recently, the nomenclature of PBD has become more varied and nuanced [4]. As the nomenclature of PBD is evolving (Table 1), the pace of adopting PBD is also increasing. Notably, individuals may follow PBD for reasons other than ethics or religion [20].

India has the largest number of vegetarians worldwide, with ~30% of the population being lacto-vegetarian [18, 19]. In Western nations, the prevalence of PBD remains far lower [21, 22], although it is rising. In Canada, for example, veganism and vegetarianism are reported by 4.6% and 7.6% of the population, respectively [22], and 37% of adults were willing to reduce meat consumption [23]. In the United States, PBD (vegan) increased by 600% between 2014 and 2018 [21]. There are demographic differences in PBD [21–23], which is most common amongst young adults [24, 25]. With the near-global rise in food prices in recent years [26], a shift to PBD may result from financial necessity. With increasing demands for PBD, non-animal protein sources are anticipated to account for one-third of the total protein market [27].

Healthcare professionals whose patients have FA and follow a PBD should provide culturally and evidence-based nutritional guidance that meets their FA requirements. This is particularly important during early childhood, when the nutritional demand is highest to support growth and development. Understanding the patient's motivation for following a PBD may help guide discussions and advice. The patient's well-being should be considered when providing dietary advice.

2 | Macronutrient Considerations for Plant-Based Diets

Macronutrients, including carbohydrates, fat and protein, are the foundation of any diet, including PBD (Figure 1). PBD are typically high in volume and fibre [28]. While individuals with FA often eat home-prepared foods [29, 30], many use free-from commercial foods, which even when plant-based, may contain excess sugar, fat and salt and may be classified as ultra-processed food [31].

2.1 | Carbohydrates

PBD are typically high in carbohydrates, from grains, legumes, fruits and vegetables [28]. Few carbohydrate sources are classified as priority or top allergens, which fall under defined food labelling practices in Australia [32], Canada [33], the United Kingdom [34] and the United States [35]. Exceptions to this are wheat [32–36], celery in the EU and UK [34, 36], and barley, oats and rye if containing gluten, in Australia, the EU, UK and New Zealand [32, 34, 36]. Avoidance of allergenic carbohydrate sources is not trivial; the inclusion of adequate amounts of tolerated plant-based carbohydrates amongst individuals managing FA is likely to be less challenging than the inclusion of tolerated plant-based fat and protein sources.

2.2 | Fat

PBD include fats from peanut nuts, seeds, oils and some fruit (avocado), including some that are common allergens (Figure 1). In infants, fat requirements range between 30% and 45% of energy, which may be difficult to achieve on a PBD [37], and which may impact the metabolism of fat-soluble vitamins. Appropriate quantities of dietary fat are achievable across the ages, in the appropriate proportions of type of fat, and the appropriate ratios of essential fatty acids. However, caution is warranted to ensure that plant-based fat sources are safe for an individual comanaging FA. Peanuts and tree nuts contain abundant levels of monounsaturated fat [38, 39], but are common triggers of allergic reactions [40–42], including anaphylaxis [42–44].

2.3 | Protein

Many western dietary patterns feature high intakes of animal-based protein, including milk, eggs and meat. There is ongoing debate about the physiological effects of animal- vs. plant-based protein sources. The latter appear to contribute to greater health benefits [45] and are nutritionally adequate for all ages, including children, when well-planned (i.e., meeting nutritional requirements and promoting normal growth and development) and routinely assessed by healthcare professionals knowledgeable in the area [8, 12, 46]. Milk and egg are known triggers of allergic reactions, and some PBD may include these foods [17].

TABLE 1 | Selection of plant-based diets and corresponding definitions.

Plant-based diet	Definition
Fruitarian	Fruit only; possibly nuts, seeds
Pescatarian	Fish only, no other meat; milk and egg
Plant-based/Flexitarian	Primarily (not exclusively) plants
Raw food	Only raw, fermented foods; not heated >47°C
Vegan	No animal products of any kind
Vegetarian	
Lacto-ovo	No meat or fish; will consume milk and egg
Lacto	No meat or fish; will consume milk, not egg

Owing to its near-ubiquity in many food supply chains, milk is the food requiring the most planning and time needed for avoidance, and causing the most anxiety amongst those managing multiple FA [47].

Recently, the early introduction of milk, egg and other common allergens, including peanut, has received considerable focus. Indeed, allergy and paediatric organisations globally recommend early introduction of peanut around ages 4–6 months or when the infant is developmentally ready, and not delaying other allergens beyond the age of 6 months [48–51]. Food allergen immunotherapy, including oral- [45] and sublingual immunotherapy [52] for milk and egg allergy, has shown promising results. However, both early introduction and food immunotherapy require considerable parent/caregiver effort, with the latter also being resource-intensive for healthcare professionals. Moreover, infrequent ingestion of a given food may also increase the risk of FA [53, 54]. Thus, healthcare professionals and parents/caregivers adhering to a PBD are encouraged to engage in shared decision-making about the introduction or efforts to introduce foods not commonly found in the family's diet.

3 | Micronutrient Considerations for Plant-Based Diets

Essential micronutrient demands exist within a PBD, including the minerals iron, zinc, iodine, calcium and magnesium, and vitamins A, B2, B12 and D. Mineral and vitamin content is often lower and/or their bioavailability is poorer in PBD, compared with diets that include animal products (Figure 2). Notably, those with FA are more prone to micronutrient deficiencies [55, 56] than those without FA.

Nutritional deficiencies impact the immune system, leading to immune priming and inflammation [57–59]. Malnutrition, including undernutrition, hidden hunger (i.e., micronutrient deficiencies) and overnutrition, per se [60, 61], specifically the lack of iron [62] and vitamin A [63], may result in Th2 skewing [64–67]. As the Th2 milieu is the prerequisite for allergic sensitisation and IgE formation, any malnutrition may foster the development of FA [68–71].

Other pivotal nutritional aspects to consider are physiologic uptake routes of food via the blood or lymph and that in (subclinical) inflamed settings, the malabsorption of several micronutrients may occur. In obese persons, subclinical inflammation is present, reducing their ability to effectively absorb minerals [72].

3.1 | Considerations for Increasing the Bioavailability of Minerals and Vitamins From Plant-Based Diets

3.1.1 | Minerals

3.1.1.1 | Iron and Zinc. The most common nutrient deficiency in the world is iron deficiency and affects ~1.4 billion people [162]. The 2022 global pooled prevalence is 16% for iron-deficient anaemia and 18% for iron deficiency [163]. The prevalence of zinc deficiency is uncertain due to the lack of reliable and accepted marker but is estimated to be similarly high as for iron deficiency [164]. Zinc is strongly associated with iron as both are linked to the same food sources (meat, poultry and fish).

The dietary form of iron is crucial to increase its bioavailability as ‘free’ iron tends to generate reactive oxygen species and thus cause tissue damage. Thus, the intake of iron-rich food, whether animal- or plant-derived, should be accompanied by the consumption of antioxidants in the form of fruit and vegetables. The duodenum and upper jejunum are the main sites of iron absorption with particularly vitamin C [73], the addition of vitamin A [74], dairy products [75] and fat [76] improving its absorption [73] (Figure 2).

Dietary iron is usually categorised as heme iron and non-heme iron, with the presence of heme iron improving non-heme iron absorption and *vice versa* [77–82]. In plants, non-heme iron predominates, although soybeans also contain heme iron in the form of leghaemoglobin [83]. In meat and fish, heme iron dominates, although about 55%–60% is non-heme iron [84]. Also animal product, particularly excessive consumption of cow's milk, the most common food allergen, can contribute to iron-deficiency anaemia in children with an already low iron status

[163–165] as cow's milk contains very little iron, but binds very iron very efficiently [165–170].

Phytates and tannins present in plants bind iron [85, 86] and hinder its uptake [87] as they bind quite strongly to iron and are too large for epithelial uptake. Excessively high calcium impedes iron absorption, albeit only to a modest degree of 20%–30% [88–92]. The addition of vitamin C can triple iron bioavailability [73, 93]. Lentils contain high phytate levels [85] that can considerably decrease non-heme iron absorption [87]. The addition of oily fish and vitamin C [73] improves the bioavailability of phytate-rich diets [94].

Like iron, zinc is present in the same food sources and its bioavailability is hindered by phytates. Unlike iron, zinc absorption is not improved by vitamin C, or hindered by phenolics [65]. Principal risk factors for zinc deficiency include diets low in zinc or high in phytates and malabsorption due to diarrhoea or intestinal parasites and impaired zinc utilisation due to genetic diseases such as sickle cell anaemia and acrodermatitis enteropathica. The bioavailability of zinc sulphate, acetate and zinc gluconates seems to be greater than for zinc oxide and zinc carbonates [95], with the molar ratio of phytate:zinc >18/meal highly reducing its bioavailability in men. Including animal proteins in a meal improves zinc absorption from phytate-containing diets (e.g., rice and wheat) [96–98].

In developing countries, a major source of iron and zinc for women is bread, as are fortified wheat flour, maize flour or rice [99]. The frequent consumption of nuts [100], seeds, grains [101], oats [102] and cereals, in combination with fresh fruits and vegetables, soybean products and dairy products [103], adequately improves anaemia, even amidst subclinical inflammation. However, in patients with nut/seed and selected cereal allergies (i.e., oats, wheat), many of these plant-based sources may need to be eliminated, increasing the risk for zinc and/or iron deficiency.

Fat contributes to the iron absorption by favouring its uptake via the lymphatic vessels; therefore, a low-fat diet, which may occur in a poorly planned PBD and FA, can considerably reduce the bioavailability of iron, zinc, manganese and calcium [76].

3.1.1.2 | Calcium. Calcium is required in greater quantities than other micronutrients. Calcium is richly present in dairy products [104], contributing over 50% of total calcium in many diets, and in fish and meat. Some plant foods, including legumes, green leafy vegetables and broccoli, can also contribute to dietary calcium, but the content is lower and the bioavailability can be low if the concentration of oxalate or phytate is high. Calcium salts that are recommended for infant formulas and complementary foods include calcium carbonates, calcium chloride, calcium citrate, calcium malate, calcium gluconate, calcium glycerophosphate, calcium lactate, calcium phosphates (mono-, di- and tribasic), calcium hydroxide and calcium oxide [105].

Calcium in plant-based foods is often bound by oxalate and phytates, which lowers calcium bioavailability [106]. In the UK, it is compulsory, and in the US, it is optional, to fortify white and brown bread (but not wholegrain) with calcium carbonate. Calcium gluconates and citrate malate are often used to fortify juices. The top plant-based calcium foods with good bioavailability are kale, finger millet and fortified white bread (with calcium carbonate) [107]. The foods with the lowest calcium bioavailability are spinach, tofu, dried figs and tahini [107]. There are concerns about lower bioavailability of calcium in plant-based beverages such as soy-, rice-, oat- and almond milk, compared with skimmed milk [94]. The latter are common alternatives in patients with a cow's milk allergy and require further research to optimise calcium absorption. The World Health Organization (WHO) recommends calcium fortification in these beverages with calcium gluconate or lactogluconate to improve the quality of soy beverages, to which potassium citrate or hexametaphosphate may be added as stabilisers.

3.1.1.3 | Magnesium. Adequate magnesium intake is pivotal; insufficiency is strongly associated with inflammation. Dietary sources of magnesium are more varied; dairy products, vegetables, grains, fruits and nuts are important contributors, although oxalate and phytates may also lower magnesium bioavailability due to the formation of large complexes [108]. Phytates can be destroyed to smaller units by simple cooking (seeds [109], beans [110]) thereby improving the bioavailability of minerals. However, soaking in acidic liquids, sprouting and lactic acid fermentation (sourdough [111]) is more effective than cooking [112]. Herbal teas can contain high levels of water-extractable magnesium [113], calcium and iron [114].

3.1.1.4 | Iodine. Iodine is primarily stored in the thyroid glands; deficiencies particularly affect young children and pregnant women. The most devastating and preventable outcome of iodine deficiency is cognitive impairment. Iodine deficiency during the critical window in brain development, from foetal development to the third month of life, can result in thyroid failure and lead to irreversible alterations in brain function, though 'milder' iodine deficiencies still will result in neurological and intellectual deficits [115]. Individuals following a PBD are at a greater risk of being iodine deficiency, particularly in countries without a fortification programme or where animal products, that are naturally high in iodine or in which farming practices enrich the animal products with iodine (i.e., cow's milk) are not consumed [116, 117]. Additionally, fortification programmes frequently include iodised salt, which should be avoided particularly in young children, although this increases the risk of iodine deficiency in children with a cow's milk allergy on unfortified plant-based milks [118]. For PBD, seaweed and fortified salt represent major food sources for iodine for older children and adults. Iodine is also found in fortified foods such as breads, cereals and milk.

3.2 | Vitamins

3.2.1 | Vitamin A

Vitamin A is important as deficiencies are associated with 'all-cause mortality and morbidity' [119] Retinoids and provitamins are absorbed in the intestinal lumen and converted to retinyl esters, before being packed into chylomicrons for distribution via the 'lymph path' [120]. Dietary intake alone may be insufficient; in the absence of oils, vitamin A may not be absorbed, with some

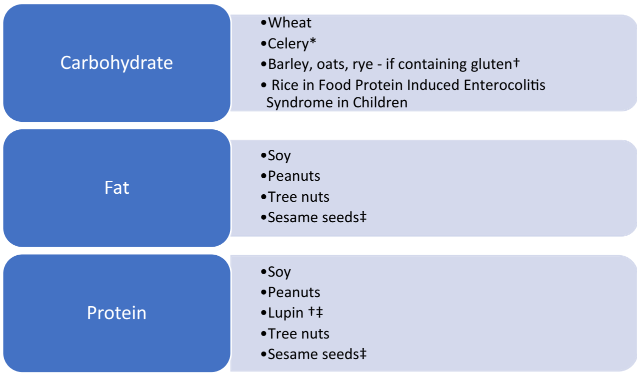

FIGURE 1 | Major plant-based food allergens, by macronutrient type, with consideration to mandatory allergen labelling requirements. *In the European Union [36] and the United Kingdom [34] only. †In Australia and New Zealand only [32]. ‡Many seeds have been associated with allergic reactions, including anaphylaxis. The exclusive mention of sesame seed in Figure 1 reflects that sesame seed in particular is a top allergen in Australia [32], Canada [33], the European Union [36], New Zealand [32], the United Kingdom [34], and the United States [35].

evidence suggesting that this may increase the risk of food hypersensitivity and allergic sensitisation [121].

Although vitamin A is present in animal and plant-based foods, individuals with a low intake of dietary fat and consuming most of their vitamin A needs from provitamin carotenoid sources are at greatest risk of vitamin A deficiency [122]. Provitamin carotenoid sources include orange and yellow vegetables, for example, carrots, sweet potato and winter squash, which are rich in alpha- and beta-carotenes. Green vegetables, like broccoli and kale, also contain carotenes, albeit in lesser amounts than orange and yellow vegetables. The conversion rate of beta-carotene to retinyl-ester is 12:1 and/or provitamin A carotenoids 24:1 is very low [122–124]. Adding oil at the time of serving improves the bioavailability of α-carotene, lycopene, phylloquinone and retinyl palmitate in a linear fashion [125] leading to a conversion of up to 2:1. Other deficiencies, including iron, calcium and magnesium deficiencies, may negatively impact carotenoid bioavailability [126]. Grinding and certain cooking methods as steaming, boiling and stir-frying with oil (but not deep-frying) seem to facilitate absorption. Combining different food sources including protein-rich meals improves vitamin A absorption [127, 128] (Figure 2).

3.2.2 | Vitamin B2

Vitamin B2, or riboflavin, is a water-soluble B vitamin, which helps the body to convert food into usable energy, is involved in red blood cell production and contributes to the maintenance of a healthy skin, hair, nails and vision. Vitamin B2 deficiency can cause inflammation of the skin, tongue, corners of the mouth and eyes; this deficiency is particularly common in areas with low meat and milk/dairy intakes.

Although vitamin B2 from animal sources has a higher bioavailability than vitamin B2 from plants, plants are nonetheless good sources. However, in plants, vitamin B2 is often bound to fibres and phytates decreasing its bioavailability. Vitamin B2 is highly sensitive to light, but is relatively resistant to heat, including some cooking methods such as steaming, stir-frying or microwaving with minimal water. Other cooking methods that involves discarding the cooking water can lead to vitamin B2 loss in boiled vegetables as it is water-soluble.

3.2.3 | Vitamin B12

Vitamin B12, also named cobalamin, warrants careful consideration for those following a PBD who are also allergic to cow's milk and egg, as this vitamin is almost exclusively found in animal-based foods. Vitamin B12 deficiency can lead to macrocytic (megaloblastic anaemia), which affects DNA synthesis, energy production, cell division and erythropoiesis. Moreover, neurological symptoms, without developing anaemia, maybe more commonly observed in vitamin B12 deficiency [129]. People at risk are those with a low dietary intake of animal-source food [130, 131]. Deficiency can also result from malabsorption due to gastric atrophy and long-term use of proton pump inhibitors, commonly used in food protein-induced gastroesophageal reflux disease and eosinophilic oesophagitis [132]. Unlike iron, vitamin C does not reduce the bioavailability of cobalamin [133–135]. While some plant-based foods, like nutritional yeast, tempeh and certain algae contain vitamin B12, the absorption rate of vitamin B12 from these foods compared with animal-based foods is very low (5%–10% vs. 0%–90%, respectively) [136, 137].

3.2.4 | Vitamin D

Vitamin D is a fat-soluble vitamin and essential for maintaining healthy blood levels of calcium and phosphate [138, 139] in the blood, which are, in turn, needed for the mineralisation of bones, muscle contraction, nerve conduction and general cellular function in all cells of the body. Vitamin D also regulates cell differentiation and hormones, including parathyroid hormone and insulin.

As vitamin D is important for bone health, severe vitamin D deficiency can cause bone diseases called rickets in infants and children, and osteomalacia in adults due to failure of the organic bone matrix to calcify. Adequate calcium intake is essential for optimal vitamin D metabolism [140], which can be challenging for individuals with a cow's milk allergy.

The diet contributes only a small fraction of vitamin D; 80% of all vitamin D is synthesised in the skin upon sun exposure as calciferol, vitamin D3. Many vitamin D-rich foods are from animal sources (Figure 2), and only limited plant-based sources exist, which include ultraviolet-radiated mushrooms, fortified cereals, fortified plant-based margarines and vitamin D-fortified plant-based beverages [141].

Thus, PBD, in combination with fortified food, provide adequate nutrition in terms of minerals and vitamins requirement. However, careful planning and awareness are essential.

Nutrients		Plant-based	Improve bioavailability with	Animal-based
Iron		nuts, seeds, grains, dried fruit, beans, soy bean flour, oats, herbs	addition of Vitamins A and C, oil/fat, dairy or soybean products	liver,meat, fish,
Zinc		seeds, beans, oats, nuts, lentils, soy*	addition of proteins, soaking, sprouting	liver,meat, fish,
Iodine		fortified salt, seaweed	addition of dairy or soybean products	salt-water fish, dairy, eggs, liver chicken
Calcium		kale, finger millet, nuts, winter squash	cooking, sprouting, fermentation	milk/dairy products, fish
Magnesium		whole grains, green vegetables, nuts and seeds, tea	cooking, sprouting, lactic acid fermentation	fish, meat, chicken
Vitamin A		orange and yellow vegetables as carrots, sweet potatoes and winter squash	grinding, steaming, boiling addition of oil	liver, meat, fish, dairy products
Vitamin B2		leafy greens, nuts, seeds and whole grains	water-soluble, light-sensitive, but heat resistant, steaming, boiling, stir-frying	eggs, meat, fish dairy products
Vitamin B12		(yeast, tempeh, algae), fortified cereals	whey proteins, sorbitol	fish, beef, dairy, eggs
Vitamin D		mushroom, fortified cereals	addition of oil, calcium (dairy products)	salt-water fish, fortified dairy products

FIGURE 2 | Sources and techniques to improve bioavailability of minerals and vitamins from plants. (images from Freepik). *See references 171, 172 for further reading on recent data on soya and phytoestrogen https://pubmed.ncbi.nlm.nih.gov/33962824/.

In recent years, concerns have been expressed around the ultra-processed nature and sugar content of some of the plant-based alternatives, which include fortified plant-based milks, cheese and yoghurt alternatives [142]. This concern of ultra-processed foods is not limited to plant-based foods but dietary intake per se. Vlieg-Boerstra et al. highlighted the importance of an immune-supportive diet in patients with allergies and recommended limiting ultra-processed foods [143]. Registered dietitians are key to perform a holistic dietary assessment on the total diet (including total refined sugar content and consumption of ultra-processed foods) and provide practical advice for patients to maintain a balance between nutritional benefit and immune support.

4 | Growth in Children, With Consideration to Food Allergy and Plant-Based Diets

4.1 | Growth and Food Allergy

Growth assessment is a critical part of a clinical assessment in paediatric FA practice [144], as growth may form part of the presenting symptoms and can be a consequence of suboptimal dietary management [145]. Height growth can be significantly impacted in children with FA [146], likely driven through a combination of an inappropriate elimination diet, micronutrient deficiencies and ongoing inflammation (i.e., skin and gastrointestinal tract) [145, 147]. Meyer et al. [146, 148, 149] found that stunting, defined by a height-for-age <−2 z-score occurred in around 10% and wasting, defined by a weight-for-height <−2 z-score in around 3% of children with FA.

4.2 | Growth and Plant-Based Diets

One of the first studies published in 1988 on 37 British children on a vegan diet and followed over several years found that height, weight, and head and chest circumferences were within the normal range for almost all children [150]. Studies involving larger cohorts were published including the Farm Study (a collective community in Tennessee that met many of its own food needs through own production), that included 404 children aged 4 months to 10 years, with 75% being vegan. That study found no evidence of marked abnormality with regard to body height or weight between enrolled children, but there was a statistically significant yet small difference in height at age 5 years and younger [151]. A Polish study of 63 and 52 vegetarian and vegan children, respectively, aged 5–10 years, also found that vegan children were shorter omnivore children [152]. However, German ViChe study on 430 children aged 1–3 years of age on a vegan, vegetarian and omnivore diet found no significant differences in weight, and height between the diet groups and indicated an average normal growth in all groups [153]. Similarly, an assessment of 248 vegetarian children from The Applied Research Group for Kids (TARGet) population study of 8907 (mean age 2.2 years) by Elliot et al. [154] found no significant difference in children on an omnivore diet. However, the ViChe study identified stunting in vegan (3.6%) and vegetarian (2.4%) children, and wasting in 3.6% of vegan children compared with 0% of vegetarian and 0.6% of omnivore children. Similarly, TARGet identified higher odds of underweight with a vegetarian diet. None of the above studies assessed the impact of dietary advice on nutritional status.

4.3 | Growth and Food Allergy and Plant-Based Diets

The overlap between a food-elimination diet for FA and children on a PBD was highlighted in a review by Protudjer and Mikkelsen [12], underscoring the concern around growth. The specific concern is that the 'double' elimination of foods for the allergy and avoiding animal-based foods may further increase the risk of poor growth. In paediatrics, the most common food allergens, include cow's milk, egg, peanut and tree nuts, soy, fish and wheat, with many of the aforementioned contributing important nutrients to the growing child's diet and being important plant-based protein sources. The German Society for Allergology and Clinical Immunology published a position paper on vegan diets and FA (the only society that has a position paper on this topic), expressing concern about nutritional adequacy and growth [155]. This position paper references the systematic review of Simeone et al. [156] on the adequacy of a PBD during complementary feeding. That study concluded that vegetarian and vegan diets cannot be recommended during complementary feeding, highlighting growth as a concern. However, only two observational studies were found suitable for inclusion on growth and the authors state the low quality of the data.

The focus for both FA and plant-based nutrition studies has been on underweight. But, overweight and obesity are observed in children with FA (8% in the study by Meyer et al.) [146]. In growth studies in children on a PBD, the prevalence of obesity was much lower, likely related to the lower energy density, higher fibre intake and overall lower refined sugar intake [157].

To date, the authors of this publication are not aware of any peer-reviewed publications assessing growth specifically in children with FA and on a PBD. However, food eliminations in children with FA do increase the risk of growth faltering; an additional PBD will lead to further dietary restrictions and thus further increase risk. It is therefore critical that all patients with FA and who also follow a PBD, see a suitably qualified dietitian/nutritionist to advise on dietary adequacy [155, 158].

5 | Guidance for Monitoring Growth and Nutritional Status

Appropriate nutritional advice and monitoring improve the nutritional status of children with FA; this is therefore an even more critical requirement in children who are also following a PBD [159]. This requires somebody with both knowledge in FA and in PBD to understand the risks to both macro- and micronutrient intake. Venter et al. recently published guidance on nutritional risk in food-allergic children, which also applies as guidance for children with FA on a PBD [160].

Growth, including weight, stature (length or height) and head circumference (age ≤2 years), should be part of standard practice with every allergy appointment. The suggested monitoring intervals for healthy children are within 1–2 weeks of birth, at 2, 4, 6, 9, 12, 18 and 24 months, then once annually for children older than age 2 years, including adolescents [161]. The frequency of measurements needs to be modified to reflect the assessed risk of growth faltering and prevents this migrating into malnutrition and affected nutritional status. Faltering growth has many definitions, but most publications suggest ≥1 z-score drop in weight-for-age over a period of time (this may vary with age) [162, 165, 166]. For undernutrition, the WHO definitions should be used, which include growth parameters >2 z-score for weight-for-height (wasting), height-for-age (stunting) and weight-for-age (underweight). Figure 3 provides guidance on different growth patterns and actions to take with these.

Children on PBD with FA have an increased risk of micronutrient deficiencies (Section 3). Many micronutrients are important cofactors for growth (i.e., zinc) and for the immune system (i.e., vitamin D). A dietary assessment of intake provides the backbone, together with growth parameters to assessing the nutritional status of the child with FA who also follows a PBD. Allergic comorbidities (i.e., atopic eczema), ongoing symptoms (i.e., diarrhoea) and medication (i.e., proton pump inhibitors) allow for further risk assessment for developing nutrient deficiencies [145]. Nutritional bloods may be required, which commonly include the following, based on published data: bone profile (including vitamin D and calcium), iron profile (including ferritin), vitamin B12 and zinc [160]. However, the aforementioned ideally should be based on an individualised assessment.

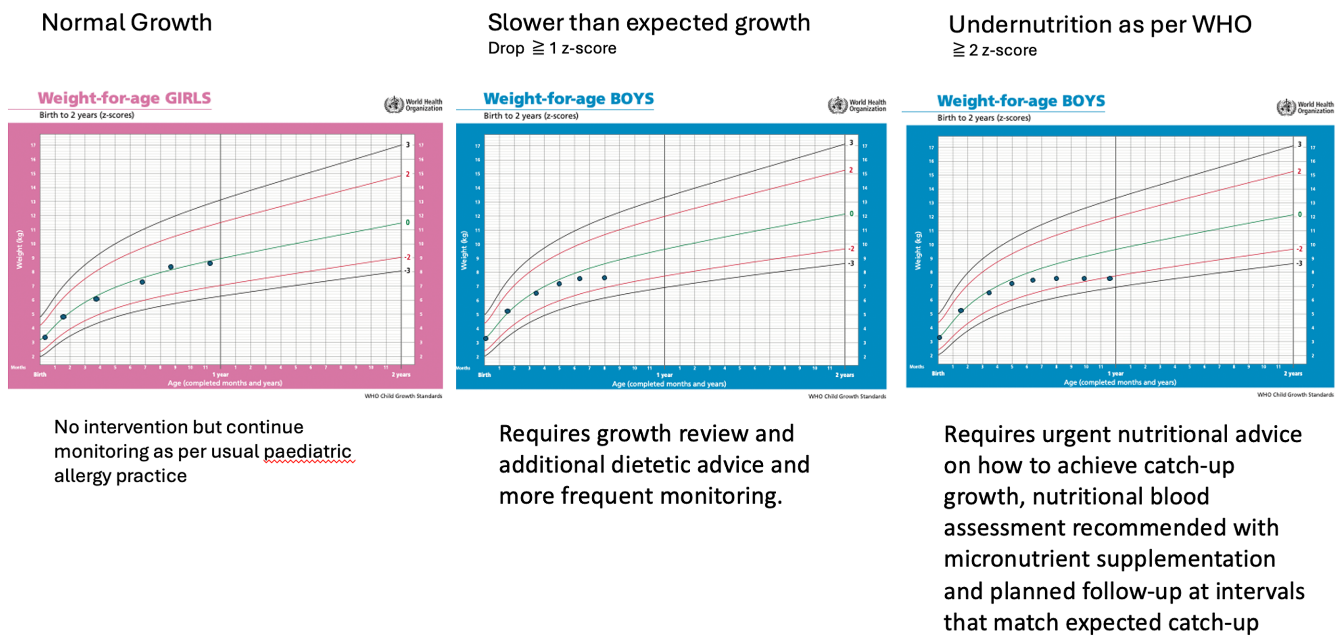

FIGURE 3 | Guidance on monitoring growth and suggested action.

TABLE 2 | Practical summary of nutritional risk assessment.

- Weight, stature and head circumference (<2 years of age) should be done at every consultation and any child with faltering in growth parameters as indicated in Figure 3 should ideally have an individualized assessment from a registered dietitian
- A clinical assessment of the child's appearance should occur as per standard practice, assessing lean and fat mass, complexion and skin tone
- A dietary intake assessment, focusing on the macro and micronutrients associated with the elimination diet and specific to a plant-based diet
- The food allergen alternatives (i.e., milk alternatives) and their nutritional contributions should be assessed to ensure that these are good replacement for the foods eliminated
- Targeted nutritional blood markers are advised when the growth faltering is present and when there are any concerns related to dietary intake and/or physical appearance

6 | Summary

The prevalence of both FA avoidance diets and PBD is increasing. Research is warranted to understand whether this change in dietary patterns will change the type of observed FA. Healthcare providers are likely to encounter patients who comanage these conditions, each of which involves dietary restrictions and a practical risk assessment (Table 2). Macronutrients of concern include fat and protein, and micronutrients that warrant particular emphasis include the minerals iron, zinc, iodine, calcium and magnesium, and vitamins A, B2, B12 and D. Growth data amongst those following a PBD is collectively inconclusive, which may be in part influenced by the type of PBD an individual follows and the support they have received. While patients managing FA and following a PBD may achieved nutritional adequacy and appropriate growth trajectories, dietary support which includes dietary assessment followed by regular monitoring is critical.

Author Contributions

J.P. coordinated and structured the manuscript, wrote the abstract, macronutrient section and the summary and provided Table 1 and Figure 1. F.R.W. wrote the micronutrient section and drafted Figure 2. R.M. wrote the section on growth consideration and provided Figure 3. All authors critically revised the manuscript for the intellectual content and approved the final version of the manuscript.

Conflicts of Interest

JLPP is the Section Head of Allied Health, and a Co-Lead, Research Pillar, for the Canadian Society of Allergy and Clinical Immunology; sits on the steering committee for Canada's National Food Allergy Action Plan; and reports consultancy with ALK Abello, Cambrooke, Novartis and Nutricia. She reports research funding from the Canadian Society of Allergy and Clinical Immunology, Canadian Allergy, Asthma and Immunology Foundation, Children's Hospital Research Institute of Manitoba, Health Sciences Centre Foundation (Winnipeg, Canada), Research Manitoba and Social Sciences and Humanities Research Council of Canada. FRW is the lead inventor of EP2894478 (applicant Biomedical International R+D, Austria), is the founder of ViaLym and has served as an investigator and received personal fees from Biomedical Int R&D, Allergy Therapeutics, Bencard Allergy and Lofarma. RM reports grants with Danone/Nutricia, honoraria from Reckitt Benckiser, Nestle Nutrition Institute, Danone, Abbott Nutrition and consultancy fees from Else Nutrition and CoMISS supported by Nestle Nutrition.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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