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BMJ Nutrition, Prevention & Health

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Alternative meat in the diets of young children

Guest Editor:
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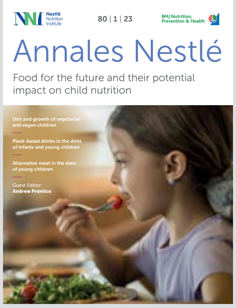

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Policy Statement

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One of the key pillars of the Nestlé Nutrition Institute is *Annales Nestlé,* a pediatric journal that has been published on a regular basis since 1942. It contains review articles on clinical practice in all fields of pediatrics and maternal health with focus on nutrition.

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Foods for the future and their potential impact on child nutrition

Andrew Prentice

Human culture is evolving rapidly, and many of these changes are affecting our attitudes to food. Foremost among these is the realisation that the threat of anthropogenic climate change—present and future—requires a radical rethinking about the contribution that food and agriculture make to greenhouse gas emissions and the need to integrate considerations of planetary health into our diet choices.

Awareness of these issues was brought centre stage by the EAT–Lancet Commission on food, planet and health that published a seminal paper on ‘Food in the Anthropocene’ in 2019.[1] Arguing that modern diets are failing to nurture human health while also damaging the planet, the commission proposed radical changes in food systems and diets requiring a major shift away from animal source foods. While not without critics, especially in Africa, the EAT–Lancet recommendations have accelerated an already growing interest in plant-based diets. In many western nations, the proportion of vegetarians and vegans is increasing and industries are innovating a diverse range of plant-based drinks and artificial meats. In the following three articles in this volume, we consider how these changes are affecting the diets of children and whether, when and to what extent novel plant-based foods can be safely introduced.

Alexy reviews recent trends in vegetarianism and veganism in children.[2] Recent reviews conclude that about 10% of adults are vegetarians in high-income countries and about 1%–2% are vegans with both proportions on the rise. Estimates for children are sparse but the comprehensive EsKiMo Study from Germany also shows a rising prevalence in the past two decades. Among adults, the motives for change include both animal welfare issues and concerns about the environment; these are often shared across family members.

Dietetic professionals in many countries accept that vegetarian and even vegan diets can be adopted for young children but great care must be taken to address the possibility of deficiencies in certain critical nutrients: protein, iron, zinc, calcium, selenium, vitamin B_{12} and vitamin D. There is little data for very young children and it would generally be considered that the greatest care should be taken in this age group if animal foods are to be withheld. For older children, analysis of recent studies revealed comparable growth between omnivore and vegetarian and vegan children, but with a tendency towards a lower fat mass in the non-meat eaters. Blood lipid profiles seem better in vegetarians/vegans, but bone density is lower. The long-term significance of these trends is not yet known and will require longitudinal studies. Alexy concludes that, if not already in place, national advisory bodies should develop detailed advice for parents choosing to feed their children on vegetarian and especially vegan diets, and such guidance needs to be actively disseminated.

Merritt addresses the complex issues of plant-based drinks that have flooded many markets in recent years.[3] This article was commissioned to discuss the use of ‘plant-based milks’ but uses the term plant-based drinks because legislation in some countries forbids them from being called milks. He starts with a clear statement that plant-based milk substitutes should never be given in infancy apart from specialised commercial soy or rice substitutes used for medical reasons. For older children, milk (usually cows’ milk) plays a prominent part in the diet in many countries and provides an important source of high-quality protein, calcium and other nutrients. Milk is not essential but requires careful dietary adjustments to adequately compensate for its absence. There are wide differences in the composition of plant-based milk substitutes (usefully tabulated in Merritt’s paper) and, as yet, there is very little information about their impact on child nutrition, except for the knowledge that children not consuming animal milks tend to grow more slowly than those that do.

As with vegetarianism, there are many and varied drivers of these food choices including concerns about animal welfare and the greenhouse gas emissions associated with dairy production. These are discussed in some detail by Merritt and some of the widely held public misconceptions are challenged. Nonetheless, there is an ever-increasing choice of alternative milks with advances in manufacture including precision fermentation that can help produce a milk substitute that would address the various concerns about cows’ milk and the current range of plant-based alternatives. Informative labelling and consumer education with respect to using such products in children’s diets will help ensure that children receive their optimal supply of nutrients.

Addressing the topic of alternative meat substitutes in children’s diets, Cerami describes the range of manufacturing innovations seeking to reproduce the organoleptic qualities of meat and fish using solely plant-derived ingredients.[4] There are four generic processes for making alternative animal mimetic foods: plant-based, mycoprotein-based, insect-based and synthetically cultured meats (and fish) products. The first two categories are typically based on soy, wheat or legume proteins with the addition of fats, carbohydrates and flavourings to mimic the flavour of meat. Imitating the texture of meat is a major challenge, sometimes overcome by using ‘scaffolding’ structures. Insect-derived proteins are conceptually attractive in terms of ease of production and their greenhouse gas footprint, but remain culturally alien in most high-income countries. Many companies are developing cultured meats and the first of these have received regulatory approval, but reducing the costs of

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production and finding substitutes for the bovine serum required for culture remain a major challenge.

It is too early to know the extent to which alternative plant-based drinks and meats will replace traditional animal-based foods and, as yet, there have been no studies of the potential outcomes for any children consuming with diets substantial amounts. It seems likely that consumption levels will increase, although at the time of writing the initial consumer enthusiasm for alternative meats has dipped to such an extent that several companies have gone into administration and others are acknowledging that the initial surge in sales has waned. Dissatisfaction with the organoleptic characteristics of such foods (texture, flavour, aroma) accounts for some of the loss of sales. An additional emerging reason is that most such foods are classed as 'ultra-processed' and consumers are aware of negative health messaging about such foods. An urgent research need in this respect is to identify the mechanisms by which ultra-processed foods may lead to harm and hence to define whether all such foods are harmful or whether the reported adverse effects are confined to certain specific food processing procedures.

Assuming that current trends towards a greater intake of plant-based foods continue, all three authors contributing to this volume have emphasised the needs for national paediatric dietetic bodies to develop clear guidelines to set any limits to intakes (if deemed appropriate) and to help parents to devise food strategies that will avoid potential deficiencies and optimise their children's growth, development and lifelong health.

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Open access Review

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Diet and growth of vegetarian and vegan children

Ute Alexy

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ABSTRACT

The prevalence of plant-based diets, that is, vegetarian (without meat and fish) and vegan (plant foods only) diets, is increasing also among children and adolescents, and energy and nutrient requirements are highest during this age. Hence the question emerges whether and, if so, how much animal-source food should be included in a healthy and sustainable diet. Recent studies, published 2018–2023, mostly showed comparable anthropometrics between omnivore and vegetarian children, however, fat mass was lower in vegetarians or vegans. Results on marker of iron status were inconsistent. Vitamin B12 status was lower without supplementation, but did not differ between groups when supplementation prevalence was high. Blood lipid profile seems to be more favourable in plant-based groups. Bone mineral density was lower in vegetarians and vegans, but differences attenuated after adjustment. Nevertheless, the long-term clinical relevance of these results remains unclear. Energy intake did not differ between groups and was in the recommended range, although protein intake was lower in vegetarians and vegans. Reported calcium intakes did not differ or were lower in vegetarians compared with omnivores, and were lowest in vegans. More favourable intakes in subjects on plant-based diets were found for fibre, sugar, folate, magnesium and iron. All but one study were cross-sectional, and longitudinal studies of both vegetarian and vegan children/adolescents are required to prospectively examine associations of plant-based diets with health. Professional societies should develop country-specific food-based dietary guidelines adapted to the special dietary habits for children on plant-based diets.

INTRODUCTION

There is currently controversy about whether and, if so, how much animal-source food should be included in a healthy and sustainable diet.[1 2] This issue is particularly relevant for children.[3 4] Due to growth and development, energy and nutrient requirements per kg body weight are higher than in later, less vulnerable stages of life and malnutrition can impair growth and development, sometimes irreversibly. The suitability of plant-based diets, especially vegetarian (without meat and fish) and vegan (plant foods only) diets, in this age group, is, therefore, an unsolved issue. Hence, this review aims to describe the current evidence on growth, health and nutrient adequacy of vegetarian and vegan diets during growth.

PREVALENCE AND MOTIVES

There is an increasing prevalence of individuals consuming a vegetarian or vegan diet in high-income countries.[2 5–7] In the general adult population, it is estimated that around 10% follow a vegetarian diet, and around 1%–2% a vegan diet.[2] The prevalence among children and adolescents is not clear.[2] In Germany, results from the 2015–2017 EsKiMo II study showed a total of 3.4% vegetarians (1.5% among 6–11-year-olds; 5.1% among 12–17-year-olds). This is a clear increase over the first EsKiMo I study conducted in 2006 (1.6% vegetarians among the 12–17-year-olds; no data available for younger children). Vegetarian diets were more prevalent among girls and in children from families with high economic status.[8] These sociodemographic characteristics are consistent with data from studies of adults.[7 9]

Among adults, animal rights/welfare and ethics is one main motive to follow a plant-based diet, but also health and concerns for environmental sustainability.[10] This is in accordance with a German cross-sectional study, in which children and adolescents were asked for their primary motive to consume a vegetarian or vegan diet. The vast majority reported ethical, that is, animal rights motives (ie, rejection of mass farming, right to life for animals or an emotional attachment to animals) as the most important motive for choosing their diet (vegetarians: 70%, vegans: 69%). Environmental reasons (eg, climate protection, resource conservation) were the primary motive for only 7% of vegetarians and 5% of vegans, whereas health played a role as the primary motive for 11% of vegans (vegetarians: 2%). At least 14% of vegetarians and 13% of vegans stated that the motive for their diet was 'because the parents eat this way'. Those participants indicating the parental diet as the primary motive were significantly younger (8.2±2.2 years), whereas those indicating ethics as the primary motive were slightly older (12.9±3.7 years) than those indicating other motives.[11]

POSITIONS OF PROFESSIONAL HEALTH ASSOCIATIONS

In some countries, vegetarian and especially vegan child nutrition is seen rather critically. In Germany and Switzerland, a carefully planned vegetarian diet is considered feasible even at growing age, but a vegan diet is not recommended.[12 13] The German Society for Paediatric and Adolescent Medicine recommended a balanced, omnivore diet with a moderate consumption of meat, fish and dairy because nutrient requirements are most easily and most likely met.[9] Other professional societies conclude that an appropriately planned (or balanced) vegetarian, including vegan, diet is (or can be) healthy and nutritionally adequate in childhood and adolescence, for example, the Academy of Nutrition and Dietetics,[7] the Italian Society of Human Nutrition[14] or the Canadian Paediatric Society.[15] However, these professional societies also list potentially critical nutrients and provide detailed guidance on how to ensure that intakes meet requirements.

POTENTIAL CRITICAL NUTRIENTS

Restrictive diets, excluding animal source foods, have an increased risk of inadequate nutrient intakes, not only because a lower dietary diversity generally decreases the likelihood of adequate nutrient supply. Animal source foods are good sources of some nutrients, for example, for high-quality protein (meat, fish, dairy), riboflavin and calcium (dairy), iodine (fish, dairy), long-chain n-3 fatty acids (fatty fish), selenium (animal-source food) and bioactive compounds including creatine or taurin.[1 16] In particular, animal-source foods are the only natural source of vitamin B12.[6 9] The bioavailability of some nutrients is also higher from animal-source foods. First, because nutrients are in a readily absorbable form, such as haem iron in meat.[1 2 6] Furthermore, some plant foods contain anti-nutritive substances that impair absorption, such as phytates that inhibit the absorption of iron and zinc.[1 2 9] However, animal-source foods are also major sources of saturated fatty acids and cholesterol, contribute little to the supply of potassium, magnesium and folate, and lack many health-promoting ingredients such as dietary fibre and phytonutrients (secondary plant compounds).[1 2 17]

With a vegetarian diet, special attention should therefore be paid to a sufficient supply of iron and zinc, with a vegan diet additionally to protein, long-chain n-3 fatty acids, calcium, iodine, selenium and in particular vitamin B12 (table 1).

ACTUAL STUDIES ON VEGETARIAN AND VEGAN CHILD NUTRITION

In their 2017 review on vegetarian and vegan diets during childhood, Schürmann *et al* listed 24 publications from 16 studies published from 1988 to 2013.[18] Only two studies were found examining vegan-fed children separately. With the exception of studies in the Adventist setting, which may have some sampling bias, the samples were small and most studies were cross-sectional. Outcomes were heterogeneous. Overall, the growth and body weight of children on plant-based diets were found within the lower reference range. Studies indicated lower or similar biomarkers of iron status in vegetarians compared with omnivore groups.[18] However, since these studies were conducted, substantial changes in the food market occurred: the range of foods offered has increased, including with respect to plant-based meat and dairy alternatives.[7 19] More dietary supplements are available on the market, and the world wide web has developed into an important source of information about noteworthy aspects of a plant-based diet. However, only a few studies on modern vegetarian and vegan child nutrition have been published so far (table 2).

There was only one longitudinal study (follow-up: 3 years) with a sample of young children (6 months to 8 years) in Canada, conducted between 2008 and 2019.[5] The type of diet was self-reported by parents. Of 8907 children, 248 (2.7%) were categorised as vegetarian, of whom 25 were vegan (0.3% of the total sample). The small number of vegan children precluded a separate analysis. Although vegetarian participants were more likely to have Asian ethnicity, mean body mass index (BMI)-z-score and BMI-z-score growth rates did not differ between diet groups. Nevertheless, vegetarian-fed children were slightly less tall than the control group. However, the effect size was small and was estimated to be 0.3 cm for a 3-year-old child. Serum ferritin, 25(OH) vitamin D and serum lipids did not differ between groups. The authors concluded that there were no meaningful differences in growth or the biochemical measures assessed in this study between vegetarian or omnivore children.[5]

In a small Finnish study, 40 young children from daycare centres, including 24 omnivore, 10 vegetarian and 6 vegan participants, were examined cross-sectionally in 2017.[20] No differences in anthropometric measurements (z-scores of heights, BMI and mid-upper arm circumference) were found between groups, although protein intake (% of energy intake), calculated from 4-day estimated dietary records, was lower among vegans. In contrast, fibre and folate intakes were higher in vegans than in omnivores. Blood lipids were lower in the vegan group, vitamin A status was insufficient, but erythrocyte folate was higher. The serum concentration of vitamin B12 was adequate, and no group difference of urinary iodine concentration was found. Furthermore, untargeted metabolomics analysis showed lower concentrations of essential amino acids and docosahexaenoic acid (DHA). The authors conclude that given the observed metabolic differences, the health consequences of a vegan diet in childhood need to be clarified.[20]

Two studies on vegan and vegetarian diets in Germany were conducted by a working group to which the author of

Table 1 Potential critical nutrients in vegetarian and vegan diets during childhood and plant-food sources

Nutrient	Plant food source
Vegetarian	
Iron*†	Legumes, whole grains, pseudo-grains (eg, quinoa, amaranth), nuts, seeds, green leafy vegetables[6]*
Zinc*	Nuts, seeds, whole grains, soy (tofu, tempeh)[7]
Vegetarian and vegan	
Protein	Grain and legumes (at the best in combination to enhance protein quality), soy (attention must be paid to a sufficient energy supply)[7]
Long chain n-3 fatty acids	Plant oils fortified or supplements with DHA from single cell/micoralgae oils, or single-oil-DHA-supplements (if applicable), optimise conversion by a ratio of linoleic acid and linolenic acid of 4:1[7]
Calcium‡	Tofu calcium-set, tempeh, sesame seeds and tahini, low-oxalate green leafy vegetables (kale, brokkoli, bok choy (pak choi), mustard greens, okra), certain beans, peas, lentils, almonds and calcium-enrichted beverages,[16 45] as well as calcium rich mineral water[6]; oxalate-rich vegetables (eg, spinach) are not a good source of calcium, even if the content of this mineral is high[2 45]
Iodine	Iodised table salt, sea vegetables[7]
Vitamin B_{12}§	Fortified foods
Vitamin D¶	Fortified foods (eg, plant-based milk alternatives)
Selenium	Brazil nuts

*Phytate content in legumes and whole grains, inhibiting absorption, can be reduced by baking, fermenting, soaking, leavening and germination.[2 7]
†Organic acids (ie, vitamin C, citric, malic, lactic acid) increase bioavailability.[2]
‡Potentially critical in vegetarian diets when little dairy is consumed.
§ Only regular supplementation ensures an adequate intake.
¶Supplementation might be needed depending on sunlight exposure and skin pigmentation.[2 17]
DHA, docosahexaenoic acid.

this article belongs: The VeChi-Diet study examined between 2016 and 2018 the diet of 430 children (127 vegetarian, 139 vegan, 164 omnivorous) aged 1–3 years using dietary records.[21–23] Although mean z-scores of parental-reported body weight and height did not differ between diet groups, a slightly higher percentage of vegan (3.6%) compared with vegetarian (2.4%) and omnivore (0%) were classified as stunted, and 3.6% of vegan, 0.6% of omnivore and no vegetarian child were classified as wasted.[22] Neither energy intake nor energy density differed between diet groups. Protein intake was lowest among vegans and highest among omnivores, but all groups exceeded the dietary reference value of 1 g/kg body weight per day by 2.3–2.5-fold. Added sugar was the lowest and fibre intake was highest among vegans.[22] Micronutrient intakes showed a significant difference between groups.[21] Vegan children had the highest intakes of folate, magnesium and iron, followed by vegetarians. Including dietary supplements, the intake of vitamin B12 was the highest too.[21] In a separate evaluation, selenium intake was estimated using a food composition database provided by the European Food Safety Authority. Although vegetarian and vegan children consumed less selenium than omnivorous children, on average, all three groups met the harmonised average requirement for selenium of 17 μg/day.[23]

Nevertheless, these results were only based on self-reported dietary intake, which is prone to bias social desirability and inaccuracies of food composition database. Hence, the VeChi-Youth-Study (conducted 2017–2019) also examined biomarkers of potential critical nutrients and blood lipids in a sample of 401 German children and adolescents aged 6–18 years.[11 24 25] In this study, the SD score of BMI did not differ between vegetarian, vegan and omnivore participants.[24] Vegans had no higher rates of iron deficiency anaemia, but ferritin levels were slightly lower,[24] which might be beneficial for long-term health.[2] Vegans had the lowest non- high-density lipoprotein (non-HDL) and low-density lipoprotein (LDL) concentrations in comparison to vegetarians and omnivores. A high prevalence (>30%) of 25-OH vitamin D3 and vitamin B2 concentrations below reference values were found irrespective of the diet group.[24] The food intake pattern of vegan children and adolescents was characterised by higher intakes of whole grains, legumes, nuts and plant-based milk alternatives than those of vegetarians. However, vegetarians in this study also consumed significantly less dairy than the omnivore control group.[11] As the affordability of such a plant-based food pattern is repeatedly debated, a further evaluation estimated the food costs of the three diet groups using

Table 2 Studies with vegetarian (VG), vegan (VN) and omnivore (OM) children and adolescents (2018–2023)

Reference	Study sample (design)	Methods	Main results
Ambroszkiewicz *et al*[28]	n=76 (4–9 years), thereof n=51 VG, n=25 OM (cross-sectional)	Anthropometric measurements, dietary recalls, blood samples: amino acid concentrations, 25(OH)D, parathormone, marker of bone metabolism, albumin, prealbumin	VG had comparable energy intake and lower intake of protein, amino acids and calcium, intake of fibre was higher. Blood concentrations of albumin, valine, lysine, leucine, isoleucine were lower, of C-terminal telopeptide of collagen type I (CTX-I) higher in VG; no difference was found in parathormone, IGF-I and osteocalcin concentrations.
Ambroszkiewicz *et al*[29]	n=105 (5–9 years), thereof n=55 VG, n=50 OM (cross-sectional)	Anthropmetric measurements, DXA, dietary recalls, blood samples: myocine, adipokine	Comparable body weight and height, but lower fat mass in VG, similar intakes of energy and calcium, lower intake of energy from protein in VG, no difference in concentrations of mycines and adipokines, lower leptin concentrations in VG, no difference in bone mineral content.
Ambroszkiewicz *et al*[27]	n=106 (5–10 years), thereof n=53 VG, n=53 OM (cross-sectional)	Anthropometric measurements, pubertal stage, dietary recalls, DXA, blood sample: 25-OH-Vitamin D, marker of bone metabolism and leptin	Comparable body weight and height; lower % body fat, leptin and bone mineral density z-scores in VG, comparable concentrations of adiponectin, osteocalcin and C-terminal telopeptide of collagen (CTX), higher parathormone concentrations, lower protein intake in VG, similar intake of calcium.
Ambroszkiewicz *et al*[30]	n=117 (5–10 years), thereof n=62 VG, n=55 OM (cross-sectional)	Anthropmentric measurements, pubertal stage, dietary records, blood sample: adipokines	Comparable body weight and height, but lower fat mass index in VG, comparable energy intake, lower protein intake of VG, lower ratio of leptin to soluble leptin receptors and higher adiponectin/leptin ratio, higher omentin/leptin ratio in VG, no significant differences in the ratios of adiponectin/resistin, omentin/resistin, vaspin/leptin and vaspin/resistin.
Alexy *et al*[11,24,25]	n=401 (6–18 years), thereof n=149 VG, n=115 VN, n=137 OM	Anthropometric measurements, 3day-weighed dietary records, blood (haemoglobin, ferritin, folate, vitamin B2, 25(OH)D, HOLO-TC, MMA, blood lipids)	No difference of BMI, vitamin B2, 25(OH)D, triglycerides between groups, higher folate and MMA, but lower HOLO-TC in VG than in OM, lowest non-HDL and LDL in VN compared with VG and OM, highest ferritin in OM; >30% of 25-OH vitamin D3 and vitamin B2 concentrations below reference values independent from group,[24] highest intakes of vegetables, whole grain, legumes, nuts and milk alternatives in VN, less dairy intake in VG than in OM,[11] lowest estimated food costs in VG.[25]
Desmond *et al*[26]	n=187 (5–10 years), thereof n=63 VG, n=52 VN, n=72 OM (cross-sectional)	Anthropometry, deuterium dilution, DXA and carotid ultrasound	VN had lower body fat indices but similar lean mass, VG and VN had lower bone mineral content and vitamin D-status, and serum B12 (both without supplementation). Supplementation resolved low B-12 and 25(OH)D status.
Elliott *et al*[5]	n=8907 (age 2.2±1.5 years at baseline), thereof n=248 VG[1], n=8659 OM (longitudinal: 2.8±1.7 years follow-up)	Anthropometric measures, Vitamin D status, lipoproteins	No evidence of an association between VG diet and z-BMI, height-for-age z-score, serum ferritin, 25-OH-Vitamin-D, or serum lipids, but higher odds of underweight among VG.
Hovinen *et al*[20]	n=40 (median age 3.5 years), thereof n=10 VG, n=6 VN, n=24 OM (cross-sectional)	4-day food records, anthropometric measures, blood and urine samples	VN had higher intake of fibre and folate and lower intakes of energy from protein and saturated fatty acids than OM. Status of vitamin D, DHA and cholesterol (including total, LDL and HDL) of VN children were lower than those of OM, no difference in Vitamin B12 status and urinary iodine excretion.

Continued

Table 2 Continued

Reference	Study sample (design)	Methods	Main results
Weder *et al*[21 22]	n=430 (1–3 years), thereof n=127 VG, n=139 VN, n=164 OM (cross-sectional)	Dietary records, self-reported data on body weight and height	Body weight and height z-scores did not differ between groups, but more VG and VN were classified as stunted or wasted. Macronutrient pattern differed between groups, and comparison of intake with dietary references indicated vitamin D, iodine and DHA as potential critically for all participants, as well as vitamin B2, vitamin B12, calcium and iron for VG and VN children, only.

BMI, body mass index; DHA, docosahexaenic acid; DXA, dual-energy X-ray absorptiometry; HDL, High density lipoprotein; HOLO-TC, holotranscombalamin; IGF-I, insulin-like growth factor 1; LDL, Low density lipoprotein; MMA, methylmalonic acid; non-HDL, non-High density lipoprotein.

retail food prices.[25] It could be shown that the vegetarian food pattern was the least expensive compared with the omnivore and vegan diet pattern and food costs did not differ significantly between omnivores and vegans.[25]

In Poland, Desmond *et al*[26] cross-sectionally examined children aged 5–10 years (63 vegetarians, 52 vegans, 72 omnivores) using anthropometry, deuterium dilution, DXA, carotid ultrasound, fasting blood samples, dietary intake and accelerometery data. Vegetarians (−2 cm) and vegans (−3 cm) were shorter than omnivores, but the difference for vegetarians was not significant. However, height z-scores were >0 in all groups, indicating sufficient overall longitudinal growth. Also bone mineral content was lower in both plant-based groups than in omnivores, but the cardiovascular risk profile was healthier in vegans. Furthermore, vegans had lower serum vitamin B12 and 25(OH) vitamin D concentrations, but this difference was not evident in those subgroups using supplements. With respect to iron status, vegans, but not vegetarians had lower haemoglobin and ferritin levels than omnivores.[26]

Another Polish working group repeatedly recruited vegetarian and omnivore children attending a mother and child health facility and examined several aspects of metabolic health.[27–30] The most recent paper described amino acid levels and bone markers in n=51 vegetarian (of whom 9% were vegans) and n=25 omnivorous children aged 4–9 years. Apart from the bone resorption marker CTX-I (C-terminal telopeptide of collagen type I, lower levels among vegetarians), bone markers (parathormone, Insulin-like growth factor 1, osteocalcin and osteoprotegerin) did not differ significantly between the groups. Protein intake (12.8% of energy intake) was lower but adequate among vegetarians, and blood concentrations of some amino acids (ie, valine, lysine, leucine and isoleucine) were lower too.[28]

An additional study of 53 vegetarian and 53 omnivore pre-pubertal children examined the aforementioned bone markers and additionally bone mineral density in the lumbar spine by dual-energy X-ray absorptiometry (DXA). Vegetarian children had a lower percentage of fat mass and leptin concentrations. Total and lumbar spine bone mineral density z-scores were lower, and parathormone concentrations were higher than omnivores. Notably, bone mineral density z-scores were positively associated with anthropometric parameters.[27]

In another Polish sample of pre-pubertal children (53 vegetarian and 50 omnivore children, 5–10 years), there were no significant differences between adipokines (adiponectin, visfatin and omentin).[27] Also, serum levels of myokines (myostatin, irisin) did not differ between 55 vegetarian and 50 omnivore children aged 5–9 years. The observed lower leptin levels among vegetarians reflected the lower percentage of body fat.[29]

Considering all this, studies showed comparable anthropometrics between omnivore and vegetarian children.[5 20 24 27 29 30] In one study, height was lower among vegans,[26] whereas others found no difference between groups.[5 20 22 24 27 29 30] However, especially in the youngest sample, higher prevalence of wasting and stunting than in omnivore children was observed in vegetarian and vegan children[22] but the prevalence was nonetheless low, and the longitudinal study found higher odds of being underweight in vegetarians.[5] Fat mass was lower in vegetarians[27 29 30] or vegans,[26] but not in all studies.[30] Accordingly, observed leptin concentrations were lower in vegetarians.[27 29] Haemoglobin levels were comparable[24] or lower in vegans,[26] whereas ferritin was lower in vegetarians[24] and vegans[24 26] or did not differ.[5] Also, results of vitamin D status (lower in vegans[20] and without supplementation,[26] no difference between groups[5 24 27 28] or with supplementation[26]) and vitamin B12 status (lower without supplementation,[26] no difference between groups[20 24 26] or with supplementation[26]) were inconsistent. Blood lipid profile seems to be more favourable in plant-based groups,[20 24 26] but this was not observed in all studies.[5] Mean values of total bone mineral density z-score were significantly lower in vegetarian than in omnivore children,[27] but the authors did not adjust for differences in anthropometrics. In another study, bone mineral content was lower in vegetarians and vegans,[26] after adjustment for body height and weight z scores, as well as bone area, these differences attenuated to the null in vegetarians and to −3.7% in vegans.[26] Osteocalcin concentrations did not differ between groups,[27 28] and results on parathormone were inconsistent.[27 28] However, the long-term clinical relevance of these results remains unclear. Energy intake did not differ between groups[22 24 26 29] and was in the recommended range,[27 30] but protein intake was lower in vegetarians[24 26 27 29 30] and vegans.[20 24 26] More favourable intakes in subjects on plant-based diets were found for fibre, sugar, folate, magnesium and iron.[20 21 26] Reported calcium intakes did not differ[27 29] or were lower[28] in vegetarians compared with omnivores, and were lowest in vegans.[24 26]

It must be mentioned that none of these studies was representative of the population at large. This could bias the results, as families who participate voluntarily in scientific studies may have better health awareness than the overall population. However, due to the low prevalence of vegetarian and in particular vegan diets, conducting a representative study would be not feasible and too expensive. Furthermore, only randomised trials could detect the causal effects of plant-based diets on nutrient adequacy and health, but such studies are not possible in children for ethical and compliance reasons. It would be desirable to have more data from prospective, longitudinal studies, as currently, only one longitudinal study with vegetarian-fed children is available. In addition, not all studies presented here distinguished between vegetarian and vegan diets. For the development of science-based food-based dietary guidelines (FBDGs), the development of public health measures for vegetarian and vegan families, and to elucidate divergent results of nutritional status between studies, the description of food intake patterns and supplementation habits would be useful. Studies on vegetarian or vegan diets during weaning are lacking up to now.

DIETARY SUPPLEMENTS

Although dietary supplements, in particular vitamin B12, are recommended in a vegetarian and specifically vegan diet both among adults and children, data on the prevalence of use within plant-based diets are scarce. Sutter and Bender stated that a third to a half of all vegans use supplements,[17] and awareness about vitamin B12 is assumed to have strongly increased over the last decades.[6] Nevertheless, only very few studies with paediatric samples reported exact data on supplementation practices, even when nutrient status was the main aim.[31] In some studies, the use of supplements was even an exclusion criterion in recruitment.[18] In one recent Polish study[26] (table 2), analyses of vitamin D and vitamin B12 status were presented among vegetarian and vegan children stratified by the use of supplements. Accordingly, 44% of vegans and 34% of vegetarians supplemented vitamin B12, and 32% of

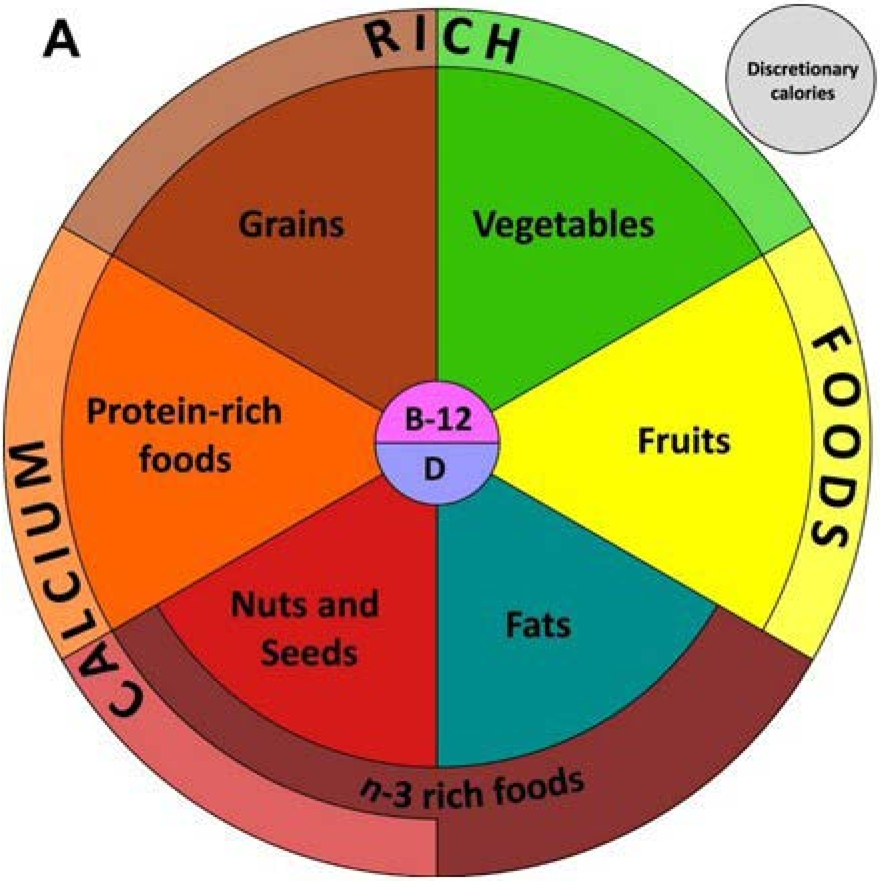

Figure 1 The VegPlate Junior as an example for a vegan Food Based Dietary Guideline for children and adolescents as published by Baroni and Battino.[32]

vegetarians and 33% of vegans supplemented vitamin D.[26] In German studies, the supplementation rate in particular of vitamin B12 was substantially higher: In the German Vechi Youth study, the vast majority of participants supplemented vitamin B12 (vegans: 88%, vegetarians: 52%), and a substantial part of the sample also vitamin D (vegans: 54%, vegetarians: 27%).[24] In the Vechi Diet study with a younger sample, 97% of vegans and 35% of vegetarians, reported the use of vitamin B12 supplements.[21] In Finland, 83% of vegans and 40% of vegetarians reported the intake of vitamin B12 supplements (vitamin D: 90% of vegetarians and 100% of vegans).[20] The reasons for the different study results are unclear. It is possible that families in different countries have different levels of information about the need for supplementation, or this is the result of selection bias.

However, there is a lack of scientific knowledge about the optimal dosage of vitamin B12-supplements in a vegetarian or vegan diet due to the high variability of absorption attributable to the frequency of intakes.[32] The Italian Society of Human Nutrition suggests vitamin B12 either one daily single dose of 5 µg (6 months to 3 years), 25 µg (4–10 years) and 50 µg from 11 years onwards. Alternatively, daily multi-doses of 2×1 µg (<4 years), 2×2 µg (4–10 years) and 3×2 µg (>11 years) are suggested.[14] The Canadian Paediatric Society suggests 5 µg to 10 µg of a daily supplement for infants, children and adolescents,[15] whereas the German Society for Paediatric and Adolescent Medicine recommended 5–25 µg/day, depending on a person's vitamin B12 status and age.[9] Although there is no upper limit on vitamin B12-intake and excessive vitamin B12 intake is generally considered safe,[6] a maximum limit in dietary vitamin B12-supplements of 25 µg was proposed for adults.[33] An alternative supplementation strategy, the use of vitamin B12-fortified toothpaste, has been validated in adults,[34] but not in children.

PLANT-BASED DIETS AND LONG-TERM HEALTH

Studies on the long-term health of vegetarian and vegan-fed children are lacking because of the long latent period of non-communicable disease. However, it is well accepted that atherosclerosis starts in childhood.[35] Compared with omnivore diets, plant-based diets have been associated with substantial reductions in modifiable risk factors in adults, including atherogenic lipoprotein concentrations, blood glucose, inflammation and blood pressure.[2] The obesity risk is also reduced,[2] with differences in BMI at least partially attributable to an overall healthier lifestyle.[16] This evidence among adults is consistent with the results of some of the studies listed in table 2, which reported lower fat mass percentages[26 27 29] and more favourable blood lipids[20 24 26] among vegetarian and vegan than in omnivore children.

However, one potential long-term risk with a plant-based diet is bone health. In a recent review, a meta-analysis of 20 studies including 37 134 participants indicated that vegetarians and vegans had lower bone mineral density at the femoral neck and lumbar spine compared with omnivores. Furthermore, vegans had higher fracture rates, indicating clinical relevance.[36] Although at least in part the results might be attributable to differences in anthropometric variables,[37 38] particular attention should be paid to nutrients that are relevant for bone health and potentially critical in vegetarian and vegan diets, such as protein, calcium and vitamin D.[39] This is especially important for children and adolescents, as bone mass accumulation reaches its maximum during early adolescence (9–14 years among girls and 11–16 years among boys) and a high peak bone mass is protective against later osteoporosis and fractures.[39]

In adults, fracture incidence was reduced regardless of a dietary pattern when calcium intake was at least equal to the estimated average requirement of 525 mg/day.[40] Adequacy of vitamin D status supports the absorption of calcium. Whether vegetarian or vegan children should routinely take a vitamin D supplement is not yet answered conclusively.[2 17] In the Adventist Health Study 2, a combination of both calcium and vitamin D supplementation, the elevated risk for bone fractures among vegans disappeared.[41] Nevertheless, bone health is affected by more than these two nutrients, for example, protein intake and dietary acid load. Repeated bone density measurements in children and adolescents who have been consuming a plant-based diet for a longer period would be desirable.

FOOD-BASED DIETARY GUIDELINES

Not every plant-based food pattern is healthy[42] and provides sufficient energy and the full spectrum of nutrients. Deficiencies can occur when vegetarian or vegan diets are not well planned, specifically in the paediatric population. Hence, food based dietary guidelines (FBDG) are necessary to inform families about the selection and combination of plant foods and dietary supplements, if necessary, in particular as motivations to follow a plant-based pattern are not necessarily health-based. Nevertheless, only few plant-based dietary guidelines for children and adolescents exist up to now.[43]

The VegPlate Junior (figure 1)[32] provides recommendations for six plant food groups (ie, grains, vegetables, fruits, fats, nuts and seeds and protein-rich foods). On a second level, emphasis was laid on n-3-rich-foods and calcium-rich foods. Supplementation of vitamin B12 and vitamin D is mentioned, too. The VegPlate Junior is based on a selection of the most representative plant foods from the Mediterranean tradition. Dairy and eggs are considered optional. This FBDG was designed to fulfil the Italian and US Dietary Reference Intakes and hence meet all the criteria defining a vegetarian or vegan diet as well-planned.[32]

The Canadian governmental health recommendations take a different approach and issue one guideline from the age of 2 years[44] which can result both in omnivore, vegetarian, or vegan dietary patterns. The Canadian food guidance plate comprises only three segments: vegetables and fruits (half of the plate), whole grain foods and protein foods (a quarter of the plate each). In the protein food group, legumes (beans, peas and lentils), nuts and seeds, as well as fortified soy beverages, tofu and other soy products, are equal to animal-source foods (eggs, lean meat, fish, dairy).[44]

CONCLUSION

To stop or at least mitigate climate change, a transformation of the diet in Western countries is necessary. Above all, the consumption of meat must be reduced. Further studies are necessary to accompany this transformation and to investigate the long-term effects on nutritional status and health, especially in children. The current studies show that a vegetarian, but also a vegan diet, can ensure sufficient growth. However, especially in young children, height and weight should be monitored regularly to ensure that growth retardation is immediately diagnosed. On the other hand, a vegetarian and vegan diet might be a protective factor against overweight and obesity, not only among adults but also among children.[17] Some experts also call for medical supervision of physiologic parameters.[2 15] For this purpose, paediatricians should be provided with recommendations regarding the nutrients to be examined, including the appropriate biomarkers, as well as age-specific examination intervals. The limited data on the use of dietary supplements show large differences between countries. The goal must be that all children on vegan diets receive vitamin B12 supplements regularly, and vegetarian-fed children at least occasionally.

A vegetarian but especially a vegan diet for children should be well planned. However, it is important to acknowledge that even poorly planned omnivore diets, for example, a 'Western Style' dietary pattern comprising large amounts of animal-source foods, refined grains, salt and sugar, are not without risk[16] as the high prevalence of overweight and obesity already during the growing age show. By a combination of a wide range of plant foods and the use of supplements, energy and nutrient intake in children's diets can also be achieved by partially or even completely avoiding animal foods. Just as with omnivore diets, families need evidence-based and practical information on how a vegetarian and/or vegan diet should be composed for their children. For this, further education in the context of evidence-based FBDG is necessary. For this purpose, professional societies should develop country-specific FBDGs adapted to the respective dietary habits and the regional food market for children on plant-based diets.

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Plant based drinks in the diets of infants and young children

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ABSTRACT

Plant based drinks (PBD) do not have a role in providing nutrition to infants, other than the feeding of commercial soy and rice hydrolysate based infant formulas for medical, religious or ethical reasons. For toddlers and young children, cow's milk (CM) has a traditional place in their modern Western diet as an important source of protein, calcium and other nutrients. While milk is not essential to provide a healthy diet for young children, considerable dietary adjustments need to be made to compensate for its absence. Most PBD are not equivalent to CM in terms of inherent nutrient content and bioavailability and are more expensive. There is notable heterogeneity in their nutritional composition. According to recent studies, children who do not drink CM grow slower than those who do. There is relatively little information about the role of specific PBD in children's diets. Their impact needs to be assessed in the context of their percent of the diet, child age, health status, nutritional requirements and the composition of the rest of the diet. There are both questionable and valid reasons consumers and parents drink and provide PBD to young children, including misinformation, medical conditions, worries about toxins in CM and ethical/religious beliefs. Parents, and consumers in general, are increasingly acting on concerns about animal welfare related to modern farming practices and the adverse environmental impact of meat and dairy farming. Improvements in available alternative drinks and more informative labelling of such products are likely to be welcomed by the marketplace. The new technology of precision fermentation has the potential to lead to milk alternatives that address many of the concerns about both CM and PBD.

INTRODUCTION

There are important nutritional differences among plant based drinks (PBD) and between them and the cow's milk (CM) they may replace in the diets of children. These differences have been competently documented by a number of authors, on whose work this manuscript relies.[1–5] The North American Society for Pediatric Gastroenterology, Hepatology and Nutrition has identified nutritional concerns about the inappropriate use of PBD for children.[6] Workers in other fields have examined the environmental impact of growing plants versus dairy and meat farming and ethical frameworks that exclude animal products from human diets. This review article seeks to place what we know about the nutrition of CM and alternative PBD in the context of the reasons parents give for choosing PBD for their children.

Role of CM in the diets of children

In societies that farm milk-producing animals, animal milk has long been part of the diet, including the diet of children. Global milk availability has increased since advances in milk processing in the 19th century led to shelf-stable packaged milk products. The expansion of refrigeration in the early 20th century made safe fresh liquid milk more generally available in higher income countries. While thoughtful parents can provide children with a complete and healthy diet in the absence of CM or other animal milk,[7] it can be difficult to meet all of children's needs with a vegan diet.[8] This may be especially true when other foods in the diet come from a narrow range of foods due to availability, selective food purchasing or selective eating behaviour.

CM is commonly added to the toddler diet after the first birthday. It can replace breast milk or formula as the liquid source of nutrition in the diet. By 1 year of age, other foods generally provide about a third of the diet. At this point, kidney function has developed such that the high protein and mineral content of CM is no longer metabolically stressful. The caloric density of CM approximates that of human milk and infant formula, but protein makes up a higher percent of the calories (table 1). Over the course of the second year of life, the United States Department of Agriculture (USDA) recommends intake of 1-2/3-2 cups of CM per day (https://ask.usda.gov/s/article/How-much-dairy-should-I-provide-for-my-child-under-the-age-of-two-How-much-milk-should-my-child-drin). For 1-to 3-year-olds, milk is expected to contribute about 25–35% of calories (based on recommendations in https://www.myplate.gov/myplate-plan). Between ages 2 and 8 the recommendation is for 2 to 2-1/2 cups per day (https://www.cdc.

Table 1 Cow’s milk (CM) nutrients per 8 fl oz (237 mL) compared with human milk and a typical CM infant formula

	Human milk	Infant formula	Whole milk	2% milk	Skim milk
Energy Cal	149*	163	149	122	83
Protein g	2.53	3.2	7.98	8.2	8.37
% protein, calories	6.8	7.9	21.4	26.8	40.3
Lipid, g	10.8	8.48	7.81	4.64	0.195
CHO, g	16.9	18.1	11.3	12	12
Ca, mg	78.7	125	300	307	322
Fe, mg	0.074	2.9	0	0	0
Mg, mg	7.38	13	29.3	29.3	29.3
P, mg	34.4	69	246	251	261
K, mg	125	173	366	388	407
Na, mg	41.8	43	92.7	95.2	100
Zn, mg	0.418	1.6	1.02	1.05	1.1
Vitamin C, mg	12.3	19	0	0.488	0
B-1, mg	0.034	0.128	0.137	0.144	0.137
B-2, mg	0.089	0.224	0.337	0.334	0.32
B-3, mg	0.435	1.6	0.256	0.273	0.288
B-6, mg	0.027	0.096	0.149	0.149	0.142
Folate, µg	12.3	26	0	4.88	4.88
B-12, µg	0.123	0.48	1.32	1.34	1.42
Vitamin A, RAE	150	144	78.1†	203†	156†
Vitamin E, mg	0.197	3.2	0.122	0.073	0
Vitamin D, µg	0.246	3	2.68†	2.68†	2.68†
Vitamin K, µg	0.738	14	0.732	0.488	0

Values from US Department of Agriculture Food Data Central (https://fdc.nal.usda.gov), except as noted.
*From Reilly JJ, Ashworth S, Wells JCK. Metabolisable energy consumption in the exclusively breast-fed infant aged 3--6 months from the developed world: a systematic review. *Br J Nutr* 2005;94:56–93.
†Fortified.
Ca, calcium; CHO, carbohydrates; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; P, phosphorous; RAE, retinol activity equivalents ; Zn, zinc.

Table 2 Comparison of recommended and actual composition of 8 oz (237 mL) selected toddler milks*

Type	EFSA f/o formula†	Milk based	Soy based	Buckwheat/almond	Oat/pumpkin and hemp seeds
Energy, calories	144–168	160	160	180	140
Protein, g	2.9–4	6	4.48	5	5
% protein, calories	7–11	15	11	11	14
Lipid, g	7–9.6	5	8	9	6
CHO, g	14.4–22.4	22	17.4	19	18
Ca, mg	80	250	224	220	228
Fe, mg	0.5–1	2.5	3.2	4	1
Mg, mg	8	20	18.6	60	
P, mg	40	187	125	180	
K, mg	128	550	209	310	100
Na, mg	40	100	64	55	50
Zn, mg	0.8	0.75	1.44	2.5	
Vitamin C, mg	6.4	7.5	19.2	4	
B-1 mg	0.064	0.13	0.128	0.200	
B-2 mg	0.096	0.16	0.150	0.210	
B-3 mg	0.52	3.5	1.68	1	
B-6 mg	0.032	0.13	0.096	0.110	
Folate, µg	24	38	25.6	42	
B-12, µg	0.16	Not added	0.48	0.5	
Vitamin A, RAE	112	75	24	145	
Vitamin E, mg	1	1.2	4.8	3	
Vitamin D, µg	3.2	3.8	2.4	3	0
Vitamin K, µg	1.6		14.4		

*Data from labels and websites of US toddler formulas. Not all nutrient information available.
†Based on *EFSA Journal* 2014;2(7):3760. Nutrient levels are minimum unless range listed; nutrient values assume energy density of 160 cal/240 mL.[62]
Ca, calcium; CHO, carbohydrates; EFSA, European Food Safety Authority; Fe, iron; f/o, follow on; K, potassium; Mg, magnesium; Na, sodium; P, phosphorous; RAE, retinol activity equivalents; Zn, zinc.

gov/nutrition/InfantandToddlerNutrition/foods-and-drinks/cows-milk-and-milk-alternatives.html; Table 3-1 from https://www.dietaryguidelines.gov/sites/default/files/2021–03/Dietary_Guidelines_for_Americans-2020–2025.pdf). The American Academy of Pediatrics recommends that toddlers should receive whole milk, and young children skim or 1% milk, although the rationale for the recommendations for skim milk has been seriously challenged.[9 10] Infants in the second year of life are at risk of poor intakes of iron, zinc, vitamin D and essential fatty acids. Nutritionally, milk complements other foods in the diet at this age.[6] The match is imperfect.[11] Given the high density of many nutrients in CM, it remains an important part of most Northern Hemisphere early childhood diets, particularly for providing protein, minerals and selected vitamins, including vitamins A and D, when the milk is fortified.[12] In Europe, young child milks are used in some countries as an alternative to CM, with their nutritional composition thought better to complement the diet of toddlers and young children.[11] The European Society for Paediatric Gastroenterology Hepatology and Nutrition has not recommended a formulation any different from follow-on formulas. However, toddler milks are not regulated like infant formulas[13] and may not always provide the nutrient levels recommended for this age group, and often contain added sugars.[14] A few of these are plant based (table 2).

Studies have shown that linear growth tends to be faster in children who receive CM as part of their diet, as frequently documented in children with CM allergy.[15–19] Some of this effect may be related to specific nutrients rich in CM including calcium, vitamin D and riboflavin.[20] Faster growth is perceived as broadly beneficial.[21] However, there are concerns about potential deleterious effects of accelerated growth in certain circumstances, as it may be associated with obesity and metabolic syndrome.[22]

Health concerns associated with feeding CM to children

There are health reasons for not feeding CM to some children, including CM allergy, in its variety of manifestations. It is recognised in 0.5–3% of infants by 1 year of age.[23] This condition tends to resolve during childhood, including early childhood, and by 6 years, 90% have achieved milk tolerance.[24]

There are other health concerns with feeding milk to infants and children. These include iron deficiency related to the low iron content of milk and adverse gastrointestinal effects of milk, including blood loss in infants and anaemia with protein losing enteropathy in children given large volumes. Much of the world outside of populations native to western, southern and northern Europe becomes lactose intolerant in childhood.[25] This leads to symptoms in some with milk ingestion. There are rare inborn errors of metabolism for amino acids and sugars for which CM intake is contraindicated. Infants with William's syndrome should not receive vitamin D fortified milk.

Many chronic health conditions have not been shown to be associated with CM intake. Whole milk has not been associated with obesity or consistently with diabetes. Blood low density lipoprotein cholesterol is not more likely to be abnormal in children consuming milk. The adult disease most strongly associated with milk intake is prostate cancer, and this association includes milk intake during childhood. Others have recently described and summarised the relationship of these conditions to milk intake.[9 10 26–28] It is not the purpose of this article to discuss these in detail. Acne has also been linked to CM intake, but this condition usually does not manifest until later in childhood or adolescence.

Milk provides a micronutrient dense source of calories and protein. Ingestion of CM with its high levels of branched-chain amino acids, milk insulin-like growth factor-1 (IGF-1), lactose, and micro RNA stimulates insulin secretion and hepatic IGF-1 release. This activates tissue mechanistic target of rapamycin complex 1 (mTORC1) and its associated anabolic and other (potentially adverse) effects.[28] mTORC1 functions as a signalling mechanism related to control of tissue growth, metabolism, inflammation and autophagy. Chronic milk ingestion may alter metabolism in the direction of insulin resistance.[28] In early life, this mTORC1 stimulation is central to the growth and development process. Interestingly, these mTORC1 pathophysiologic mechanisms do not appear to be activated by dairy products subjected to fermentation, which substantially changes the nutrient characteristics of the milk.

CM can bring with it substances unrelated to its nutritional composition. These include antibiotics, hormones, pesticides and other toxins.[29] Recent US data in this regard are reassuring relative to the low frequency of antibiotic detection[30] (https://www.nmdrd.com/fy-21.pdf). Of note, US organic milk rarely showed any presence of antibiotics. In some other parts of the world, antibiotic residues in CM appear to be more common and of medical and public health concern.[29 31 32] Exposure to these potential contaminants can be reduced by use of organic milk.

Much of the commercial non-organic milk produced in the USA comes from cows treated with bovine somatotropin (BST). Administered BST does not transfer to milk, is digested by stomach acid (https://www.fda.gov/animal-veterinary/product-safety-information/bovine-somatotropin-bst) and is not bioactive.[33] However, the milk from BST treated cows has higher levels of IGF-1,[30] which can be bioactive, at least in the gastrointestinal tract.[34] Concerns specific to BST and its associated higher IGF-1 content can be addressed with the selection of milk from non-BST treated cows and organic milk.

Dairy cows are commonly pregnant while milked, and pregnancy related sex hormones transferred to milk appear to be bioactive.[35] Studies have shown associations of CM intake and some later adulthood sex-hormone sensitive malignancies, possibly related to milk hormones and/or the metabolic effects of CM ingestion.[9 28]

PBD

There is no regulatory standard of identity for the composition of PBD. PBD can be based on legumes (soybeans, peas), seeds (hemp, sunflower), nuts (almond, pecan, macadamia), grains (rice, oats) and pseudo-grains (quinoa, buckwheat). The beverage protein is provided by one or more of these plant sources, and they contribute other nutrients and properties to the milk. The extensive processing necessary to convert these foods to milks includes soaking, grinding, blanching, separation procedures, homogenisation, thermal processing and formulation during which nutrients and other ingredients—usually including sugar and salt[2]—are added to achieve appearance, taste and mouth feel more closely resembling CM.[2 36] The process varies with the starting plant source or plant protein source and the desired final product attributes. The bioavailability of nutrients in PBD is usually less than that for CM due to lower digestibility and factors such as phytates that interfere with nutrient absorption.[37] These anti-nutritional factors are variably affected by food processing. Food manufacturers may make more than a single milk product from a plant source, for example, almond milk with or without added sugar. Some PBD are formulated to come close to the composition and properties of CM, and others are made without additives or fortification. PBD may be available in shelf stable, refrigerated and powder formats and in bulk or single serve packaging. Some are certified organic or use organic ingredients.

The plant sources used for PBD are lower in multiple—and variable—essential amino acids, compared with animal protein sources, reflected in part by the lower Digestible Indispensable Amino Acid Score (DIAAS), and may contain anti-nutritional factors that can interfere with nutrient absorption. However, the foods from which PBD are derived play a nutritious and healthy role in the diet (table 3). The same is less often true for the derived PBDs. As an example, almonds are rich in protein, mono- and polyunsaturated fatty acids, minerals and some B vitamins and can be part of a healthy diet. A 1 oz (28 g) serving of almonds is about 28 almonds. In contrast, a cup of many of the commercial almond milks provides

Table 3 Typical nutrients in plant ingredients used to make plant based drinks compared with full cream cow's milk powder*

Per 100 g	Milk powder	Almond	Coconut	Hemp	Oat	Peas	Quinoa	White rice†	Soy
Energy, calories	500	584	354	553	379	364	368	356	449
Protein, g	26.7	21.4	3.33	31.6	13.2	23.1	14.1	7.94	43.3
% protein, calories	21	15	4	23	14	25	15	9	39
DIAAS‡	1.22	0.40	0.22–0.48	0.54	0.57	0.70	0.81§	0.47	0.91
Lipid, g	26.7	49.9	33.5	48.8	6.52	3.89	6.07	0.52	21.6
CHO, g	40	20	15.2	8.67	67.7	61.6	64.2	78.24	29
Ca, mg	833	254	14	70	52	46	47	5.8	140
Fe, mg	0	3.74	2.43	7.95	4.25	4.73	4.57	1.63	3.95
Mg, mg	80	258	32	700	138	63	197	32.2	228
P, mg	667	503	113	1650	410	334	457	126.4	649
K, mg	1783	733	356	1200	362	852	563	127	1360
Na, mg	367	<2.5	20	5	6	5	5	0.66	2
Zn, mg	3	2.86	1.1	9.9	3.64	3.49	3.1	1.56	4.77
Vitamin C, mg	8.6	0	3.3	0.5	0	1.8		0	4.6
B-1, mg	0.26	0.205	0.16	1.28	0.46	0.719	0.360	0.05	0.427
B-2, mg	1.48	1.14	0.02	0.285	0.155	0.244	0.318	0.05	0.755
B-3, mg	0.93	3.62	3.77	9.2	1.12	8.61	1.52	1.69	1.06
B-6, mg	0.33	0.137	0.101	0.6	0.1	0.14	0.487	0.12	0.225
Folate, µg	37	44	26	110	32	15	184	9.32	205
B-12, µg	3.25	0	0	0	0	0	0	0	0
Vitamin A, RAE	501.5¶	0	0	3.3	0	30	1	0	0
Vitamin E, mg	0	25.6	0.24	0.8	0.42	0.12	2.44	0.06	0.85
Vitamin D, µg	8.33¶	0	0	0	0	0	0	0	0
Vitamin K, µg	2.2	0	0.2		2	15.9	1.1	1.5	37

*Data from US Department of Agriculture Food Central (https://fdc.nal.usda.gov) where available and supplemented from product labels, websites and peer reviewed publications; values vary by specific commodity.
†Brown rice has higher mineral content.
‡DIAAS; most values from Herreman L, Nommensen P, Pennings B, *et al*. Comprehensive overview of the quality of plant- and animal-sourced proteins based on the digestible indispensable amino acid score. *Food Sci Nutr* 2020;8:5379–91.
§DIAAS not available. (Protein Digestibility Corrected Amino Acid Score; PDCAAS).
¶Fortified.
Ca, calcium; CHO, carbohydrates; DIASS, Digestible Indispensable Amino Acid Score; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; P, phosphorous; RAE, retinol activity equivalents; Zn, zinc.

the protein equivalent of four almonds (figure 1). Sugar may be added for flavour and vegetable oils for energy and essential fatty acids. Fortification is often the source of many of the nutrients claimed on the nutrition label. Fortified nutrients, notably calcium, have uncertain physical stability and bioavailability in the final matrix. Fermentation of plant ingredients, and including more than one plant source, may improve taste and nutrient content and availability.

The production of PBD generally requires sophisticated food processing machinery and know-how, making plant milks more expensive than CM.[38] PBD may be categorised as ultra-processed drink products using the NOVA system of food classification.[39] NOVA was developed in support of the United Nations Sustainable Development Goals and provides one means for categorising foods relative to their contribution to diet quality, impact on malnutrition and the sustainability of food systems.[40] Ultra-processed foods are manufactured from substances derived from foods and other organic sources and are ready-to-consume. They often contain flavouring agents, stabilisers, colouring agents and food processing aids such as emulsifiers. Ultra-processed foods now make up a high percentage of the diet of high-income (developed) countries (estimated at 67% for US youth)[41] and an increasing percentage of the diet of low- and middle-income (developing) countries.[42] Epidemiologic studies link ultra-processed foods to poorer diet quality and the rising level of chronic non-communicable diseases including obesity, dyslipidaemia and metabolic syndrome.[42] Avoidance of

Figure 1 Comparison of a serving of almonds with the almonds in an 8 oz (227 g) serving of almond drink*. *Not representative of all almond drinks.

minimally processed CM in favour of PBD, that may be classified as ultraprocessed, may entail its own potential diet-related morbidity or add to any attributable to ultra-processed foods. Some countries are now implementing efforts to suppress the incursion of ultra-processed foods into their food supply.

Plant based infant formulas and PBD for infants

For infants, the universally preferred and recommended milk is own mother's milk. Current recommendations are for feeding human milk for at least 6 months and up to 2 years or longer.[43] Adherence to these recommendations is variable from country to country and within countries related to breast milk supply, maternal preferences and socioeconomic variables, including employment outside of the home and formula marketing practices. Most US infants receive a milk other than breast milk before the end of the first year of life.[44] When available, the recommended breast milk substitute for infants is an iron-fortified CM based commercial infant formula. Through the first year of life, breast milk and/or infant formula remain the dominant and preferred source of nutrition. Unmodified CM is not recommended in the first year of life due to its much higher protein and mineral content, the relatively low absorption of butter fat, the low content of essential and long chain polyunsaturated acids, its low iron and zinc content, and its association with faecal blood loss.

Few plant based protein sources have been utilised to manufacture infant formulas. Soy protein has an extended history of safe use. More recently, rice protein hydrolysate formulas have become available in a few European countries. Plant based infant formulas are not the first choice for infants with CM allergy.[24 45] However, soy formula is effective for managing immunoglobulin E (IgE)-mediated CM allergy. Rice protein hydrolysate formulas can be used in all forms of CM allergy. Both are suitable alternatives when parents want a vegan formula for their infant. They can also be used in galactosaemia and alactasia, as they are lactose- and galactose-free. Some expert groups advise that soy formulas not be fed to infants less than 6 months of age.[24] Low level concern persists regarding possible adverse effects of the phytoestrogens in soy formula on female reproductive development.[46]

Marketed soy protein based and rice hydrolysate based formulas are supplemented with their limiting amino acids to bring their protein quality closer to CM. Soy formula contains added methionine, and rice hydrolysate formula contains added lysine, threonine and tryptophan. Both support satisfactory weight and length gain when provided as the sole source of milk.[47 48] Soy protein meets the protein efficiency ratio quality factor for US infant formulas under the Infant Formula Act, and soy and rice hydrolysates are approved protein sources for infant formulas under European Union (EU) regulations.

Multiple adverse events have been reported, including malnutrition and micronutrient deficiencies, in infants fed other PBD not meeting nutritional standards for infant formulas.[49] Other specific adverse metabolic events have been associated with specific PBD, for example, oxalate kidney stones and metabolic alkalosis with almond milk. Concern persists regarding the arsenic content of some rice milks. Given the strong global recommendations for breastfeeding in infancy, the general availability of commercial infant formulas in high- and middle-income countries, and the mismatch of infant nutritional needs with the nutritional profile of most PBD, other than commercial soy and rice hydrolysate infant formulas, PBM have no nutritional role to play in the infant diet.

PBD for toddlers and young children

PBD are not generally designed specifically for children. The few US products that are marketed for children range from nutritionally complete to lacking in multiple nutrients present in CM. PBD have to taste good or children will have to be very hungry to accept them. However, making beverages sweet or improving taste with salt are not advantageous to health. Making alternative drinks that are both healthy and attractive to children has long been a challenge in developing nutritious alternative drinks for this age group.

PBD do not generally match CM in nutrient content, quality and bioavailability, except for iron, which CM lacks. A consortium of expert groups in North America advised against the use of PBD to replace milk in the diet of toddlers and young children (https://healthyeatingresearch.org/wp-content/uploads/2019/09/HER-HealthyBeverageTechnicalReport.pdf). Including PBD as a snack food or occasional beverage has little impact on the total diet. With the exception of soy, and a combined plant based protein toddler drink, using them as a replacement for CM poses variable nutritional challenges relative to making up the nutrients that would have been contributed by milk. Simply increasing the intake of plant based foods, without making thoughtful compensatory dietary adjustments, has the potential to place persons at risk for low intakes of calcium, protein, vitamin A and vitamin D.[50] Low iodine content is also of concern in PBD, as CM is a major dietary source, but fluoride content tends to be higher in PBD.

Generally, studies of vegan children find a lower prevalence of obesity, but evidence of nutrient insufficiency and slower linear growth compared with other children.[8,51] Not much has been written specifically about the nutritional impact of PBD and their contribution to nutritional status and growth of children. Given the heterogeneity of PBD, each would have to be studied in its own right to generate actionable nutritional information. In the EU and Canada, PBD are labelled as beverages rather than as milk. In the USA, it appears that manufacturers can continue to use the term 'milk' to describe PBD, but the label may need to clarify aspects of their nutrient content relative to CM (https://www.federalregister.gov/documents/2023/02/23/2023–03513/labeling-of-plant-based-milk-alternatives-and-voluntary-nutrient-statements-draft-guidance-for).

Tables 1 and 4 demonstrate the mismatch in the composition of CM and PBD. There is less complete information about the micronutrient content of PBD.[1,52] Energy and protein digestibility content and amino acid scores are variable and generally less than for CM.[1] Soy milks generally come closest. As of 2015, there were an estimated 150 PBD available in Europe.[53] Given PBD variability and the often limited nutritional information at the product-specific level, statements about the nutritional role of PBD as a group have the potential to be misleading.

Vegan consumerism and preferences for PBD

There are three common reasons for why plant based foods may be preferred over milk and other animal

Table 4 Exemplary plant drink nutrients per cup

	Almond	Coconut	Hemp*	Oat	Pea	Rice	Soy
Energy, calories	36.2/73.2[†]	75.6	101	120	80/120	115	129
Protein, g	1.34	0.512	1.99	3	8	0.683	8.32
% protein, calories	15/7	3	8	10	40/27	2	26
Lipid, g	2.98	5.08	4.51	4.99	4.51	2.37	5
CHO, g	0.83/10.5	7.12	13	16	0/13	22.4	12.7
Ca, mg	422	459	390	350	451	288	237
Fe, mg	0.708	0.732	1	0.288	2.69	0.488	1.27
Mg, mg	17.1	0	42	10	0	26.8	51.2
P, mg	73.2	0	250	269	396	137	161
K, mg	75.6	46.4	122	389	451	65.9	371
Na, mg	146	46.4	55.2	101	130	95.2	80.5
Zn, mg	0.415	0		0.96	0.864	0.317	0.732
Vitamin C, mg	0	0			0	0	0
B-1, mg	0	0				0.066	0.146
B-2, mg	0.081	0	0.3	0.1		0.346	0.198
B-3, mg	0.181	0		4		0.095	0.554
B-6, mg	0	0				0.095	0.129
Folate, µg	0	0				4.88	46.4
B-12, µg	0.83	1.54	0.6	1.2	2.5	1.54	0.903
Vitamin A, RAE	100	154	90	160		154	137
Vitamin E, mg	8.1	0	1	3.6		1.15	0.366
Vitamin D, µg	2.2	2.44	5	2.2	6	2.44	1.71
Vitamin K, µg	0	0			1.08	0.488	2.9

Additives commonly used in PBM:
Energy: sugar, vegetable oil; minerals: calcium, phosphorus, magnesium, sodium, potassium; vitamins: vitamin A, vitamin D, vitamin E, riboflavin, vitamin B-12; emulsifiers: lecithin; stabilisers: guar gum, gum arabic, gum acacia, gellan gum, carob bean gum; antioxidants: vitamin E; flavors: varies.
*Data from US Department of Agriculture Food Central (https://fdc.nal.usda.gov) where available and supplemented from product labels, websites and peer reviewed manuscripts; values vary by product.
†Unsweetened/sweetened.
Ca, calcium; CHO, carbohydrates; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; P, phosphorous; RAE, retinol activity equivalents; Zn, zinc.

foods (https://www.veganfriendly.org.uk/articles/ethics-of-veganism/).[54] These are (1) ethical and/or religious concerns regarding the treatment of farm animals, (2) environmental and sustainability concerns related to the local or planetary impacts of dairy (and other) animal farming with associated climate rights and intergenerational justice issues, and (3) health reasons including real or perceived illness or risk of future illness related to milk and other animal products and/or endorsement of health benefits of a plant based diet.

Animal welfare motivation

Concern over animal welfare, including dairy cows, is a strong motivator of vegan food choices. This concern is informed by increasing evidence of farm animals' ability to experience pain, suffering and the anticipation of pain, which has led to new perspectives on animal rights.[54] The degree of reduction or avoidance of eating animal products lies on a spectrum including reducetarians and flexitarians, who try to eat less animal products, ostrovegans, pescatarians, vegetarians and ultimately vegans, who seek to avoid eating all animal products[54] (see vegan friendly website cited above). Veganism can be a personal practice or one involving activism for its cause, a distinction important to some ethicists who look at the efficacy of a practice as the determinant of its ethical value. Some vegans' perspectives are nuanced by beliefs that health benefits of consuming animal products for a subset of the population (eg, CM for children at risk of impaired growth or malnutrition) outweigh otherwise cogent ethical animal welfare and/or environmental concerns.[54]

Environmental impact motivation

There are at least a billion cows in the world. One quarter of these are dairy cows. These have local (particularly water quality and eutrophication) and global environmental impacts. The dairy sector is estimated to be responsible for 4% of anthropometric greenhouse gases (https://www.fao.org/3/k7930e/k7930e00.pdf). Ruminants and their manure produce 6% of total global methane emissions.[55] Methane is a far more potent gas for global warming than is carbon dioxide, but unlike carbon dioxide it breaks down much faster with a half-life of 8.6 years.[56] Milk production also requires much more land and water than growing an equivalent amount of protein in plants, and thus decreases land and water availability for other purposes and is less sustainable.[57] The few studies of the environmental impact specific to PBD confirm their environmental impact advantages. Reducing milk—and meat—production and their environmental impact is an important consideration for reducing global warming and a motivator for some who adopt a vegan diet[56] (see vegan friendly website cited above). However, in the production of all types of foods, even within categories, there is a large range of environmental impacts, highlighting substantial gains to be made by achieving best agricultural practices.[57]

Consumer preferences

In a US national sample of parents, most parents favoured CM over PBD[58]; 22–41% of North American households buy PBD, often not exclusive of dairy products (https://plantbasednews.org/news/41-us-households-buy-vegan-milk/).[59 60] The most popular PBD are almond, oat and soy milks. Since available evidence indicates <3% of the population adheres to a vegan diet, these beverages have a far broader consumer appeal than just the vegan population. In a marketing study of adults, reasons for selecting PBD included taste, health benefits, value, source of nutrients and being all natural (https://www.fooddive.com/news/consumers-reveal-why-they-buy-plant-based-dairy-alternatives/516702/). In the US national sample study, concerns expressed about CM included the presence of hormones and antibiotics and the environmental impact of dairy farming. A focus group study of Canadian parents identified concerns regarding toxins in CM and the environmental effects of dairy farming.[60] A study of parents of young children in Miami, Florida found 88% of the parents surveyed believed PBD are nutritionally equivalent or superior to CM. Most were unaware of their energy and protein content. The Canadian study also found parental knowledge deficits regarding PBD.

Beyond PBD

The attraction for alternatives to CM largely relate to unwanted components of CM and concerns about animal welfare and the environmental impact of dairying, as opposed to any inherent value of turning plants into a beverage resembling milk. The emerging business of precision fermentation offers a novel source of milk proteins with potential to address these concerns. In this technology, genes controlling the synthesis of a CM protein are transferred to yeast. By way of example, β-lactoglobulin can be produced by cultures of the yeast, *Tricoderma reesei*.[61] Yeast with transferred bovine β-lactoglobulin genes are grown in large fermentation vats. The yeast-synthesised milk proteins are centrifuged, separated, cleaned and dried into a protein powder for use in alternative dairy products. While these proteins remain allergenic, they are free of lactose, cholesterol, hormones, pesticides and antibiotics. Dairy farming is not required for their production. The fermented proteins have the nutritional quality and the functionality of the corresponding CM protein.[61] To date, fermented milk proteins have been used in dairy products such as cream cheese and ice cream, but not in alternative milks (https://www.msn.com/en-us/news/us/moooove-over-how-single-celled-yeasts-are-doing-the-work-of-1500-pound-cows/ar-AA18vZBH). This technology provides protein, but other ingredients are needed to make a beverage. As a result, milk beverages made from these proteins may turn out to be in the NOVA ultra-processed category. The cost of proteins made by precision fermentation will need to become more competitive with current commodities, unless subsidised to achieve national or international environmental objectives. Challenges face this business in

Table 5 Beverage choices for children: comparison of potential adverse attributes

	Cow's milk	Plant based milks	Precision fermentation
Antibiotics	+[*]		
Hormones	+	(–)[†]	
Allergy and intolerance	+	(–)[‡]	+
Cholesterol/saturated fat	+[§]	(–)[¶]	
Lactose intolerance	+[**]		
Animal welfare	+		
Pesticides	+[††]	+[††]	
Inorganic arsenic		+[‡‡]	
Environmental impact	+		(–)[§§]
Taste	(–)[¶¶]	Variable	
Food functionality		+	
Nutrition		(+)[***]	
Ultra-processed		+	+
Cost		+	+

* Appears to depend on country and strength of regulations and their enforcement.
†Phytoestrogens in soy of concern to some.
‡Can be seen with soy and rarely with other plant proteins.
§Avoidable with skim milk.
¶Coconut milk rich in saturated fat.
**Most tolerate some milk and lactase available.
††Avoidable with organic products.
‡‡May be high in rice milk.
§§Environmental impacts not fully known, but seem dramatically less than dairying.
¶¶Relatively small percent of population.
***Soy milks generally considered comparable to cow milk.

scaling the technology to reduce meaningfully the planet's more than 250 000 000 dairy cattle and in formulating CM alternatives acceptable to children. One large plant under construction is estimated to be equivalent in some ways to 10 000 cows (see website cited in this paragraph). To replace 50% of the dairy cattle in the world would take 12 500 similar plants. Thus, the challenge of scaling this technology cannot be over-stated. In table 5, it can be seen that if these hurdles can be overcome, precision fermentation could offer alternatives to dairy milk that addresses many of the concerns leading to PBD development.

CONCLUSIONS

Nutritionally, many of today's PBD do not provide the same nutrition as CM for young children. Soy beverages come nutritionally close to CM and are a reasonable alternative. Others, like most almond milks, fail to fill the dietary space of CM. Organic CM, fermented CM products and future beverages based on products of precision fermentation can be attractive, as they address some specific parental concerns. For the many parents who appear to feed their children PBD due to misconceptions about risks of CM and the nutritional value of PBD, better education and product labelling strategies are needed. The rationale for preferring plant based foods over animal foods, including milk, on the basis of fewer adverse environmental impacts and food supply sustainability has been well-established. The ethical perspective that we should not be eating animals or causing them pain and suffering can be a deeply held personal view or religious tenet. For parents who exclude CM from the diet of their children on environmental or ethical grounds, better tasting alternative drinks for children that offer more complete nutrition with fewer additives and sugar will be welcome. PBD utilising more than one plant source have the potential to be more nutritionally complete with less fortification. To help those parents committed to feeding their children alternative drinks and to assure their children receive the nutrition they need, establishing a standard of identity and implementation of standard labelling for alternative child milk products could be helpful.

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Alternative meat in the diets of young children

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ABSTRACT

Alternative meat is designed to address concerns about the impact of traditional meat on the environment, animal welfare, foodborne illnesses and human health. The availability, market share and variety of substitute meat products have exploded in recent years. This review will discuss the different types of alternative meat available, the benefits and challenges associated with their production as well as the regulatory and consumer acceptance issues that must be addressed to ensure their success. Cultivated or lab-grown meat is discussed as a separate category from all plant-based meat products because its nutritional composition is much closer to traditional meat. There is limited information about specific alternative meat products in the diets of children under five and the possible role meat substitutes can play in vegetarian and omnivorous diets. When planning a diet for a young child, parents and nutritionists will need to consider the consumption of each alternative meat product in the context of the child's age, nutritional requirements, health status and the composition of their overall diet.

INTRODUCTION

Animal agriculture is a major contributor to carbon emissions, deforestation, water pollution and habitat destruction. Moreover, the meat industry is often criticised for animal welfare concerns, including cruelty and inhumane treatment of animals. To address these issues, there has been a surge in the development of meat alternatives. Alternative meat aims to mimic the texture, flavour and nutritional profile of real meat. Alternative meat has become increasingly popular as a healthier and more sustainable alternative to traditional meat, especially among adult vegans, vegetarians and flexitarians. There is a wide variety of consumer choices currently available both in terms of the type of meat substitute and the ingredients used to make the meat substitute. Depending on the country, a variety of commercially available or in-development substitutes for beef, chicken, pork and seafood exist. The types of ingredients used vary widely from plants, mycoproteins and algae to insects as well as to cultured meat from single cells. The food companies active in the alternative meat business range from small start-ups to large conventional food multinationals including PepsiCo, Nestle, Kraft/Heinz, and even traditional meat companies such as Tyson and Hormel.[1]

There are important nutritional differences among all these products and between the types of meat that they are designed to replace. The holy grail for the alternative meat industry is to completely replace traditional meat in the human diet. The intermediate aim is to partially replace traditional meat in the diet of flexitarians.[2] There is no regulatory framework that defines the composition or the naming of meat substitute products.[3]

Types of alternative meat

Plant-based products

Plant-based meat or protein substitutes are not a new concept. However, they have recently gained significant attention and investment from the food industry driven by consumer concerns about the environmental sustainability and the ethics of animal-derived foods. The manufacture of plant-based meat involves the selection of ingredients, processing and formulation. The primary ingredients used in plant-based meat are plant proteins, such as soy, wheat, mushrooms, lentils and pea proteins.[4] These are combined with fats, carbohydrates and flavourings, to create a product that closely mimics the texture and flavour of traditional meat.[5] One of the biggest challenges in developing plant-based meat is replicating the texture of traditional meat.[6] Another important challenge is its nutritional profile.[7–11] Traditional meat is an important source of protein, iron and vitamin B_{12}, especially for young children. Therefore, many manufacturers of plant-based meat fortify their products with nutrients. One unique plant-based approach involves adding an animal-like heme protein (eg, leghemoglobin) produced by genetically modified yeast to the mixture to improve the texture, taste and nutritional value of the final product.[12] Homemade and organic plant-based products are typically minimally processed, while commercially produced versions are typically heavily processed and often contain additives and emulsifiers.

Mycoprotein-based products

Mycoproteins are proteins made from a type of filamentous fungi and used to create meat-like products. Mycoprotein-based products are created by fermenting fungi with sugar, such as glucose or lactose and nitrogen-containing media.[13] The resulting product is a protein-rich mass that can be used to create meat-like products with a fibrous texture and a slightly nutty flavour profile, which makes them a good substitute for ground meat in dishes like chili and spaghetti sauce.

Insect-based products

Insect-based products are an unconventional addition to the meat substitute market.[14] The most popular insects used to create meat alternatives are crickets, mealworms and black soldier flies. Insects require little water and food to survive compared with traditional livestock and are high in protein, vitamins and minerals. These products may be locally produced at low cost.[15] The biggest challenge with insect-based products is consumer acceptance. Many people are hesitant to eat insects due to cultural and psychological factors. Edible insects are widely consumed in subtropical and tropical regions, but not in the USA and Europe.[16] Another key challenge is ensuring the safety of insect-based products. Insects can carry bacteria and other pathogens potentially harmful to humans. Special precautions must be taken to ensure that insects are not grown on contaminated food and human waste.[17]

Cultured or cell-based products

Typically, the production of cultured meat involves five steps (figure 1). Step 1 involves cell line selection and cell banking from an animal (including cows, pigs, chickens or fish). Step 2 is the proliferation stage where the cells are grown in suspension in a nutrient-rich environment in a bioreactor. Step 3 involves the differentiation and maturation of the cells into the desired tissue including muscle, fat and connective tissue.[18] In some cases, cultured meat manufacturers use a scaffold, made from plant-based fibres or hydrogels, to guide the growth and arrangement of the cells.[19] Step 4 is the harvest step and Step 5 is the packaging. In the USA, Steps 1–3 are regulated by the Food and Drug Agency. Steps 4 and 5 are regulated by the US Department of Agriculture. In Singapore, the approval process is streamlined and is entirely handled by the Singapore Food Authority. Additional regulatory frameworks are used and are under development by other countries and by the WHO.

The main challenges of cultured meat are how to make the scale-up process cost-effective, energy-efficient and sustainable.[20] A recent analysis tried to understand, model and predict the environmental impact and financial considerations of cultured meat. While laying out the

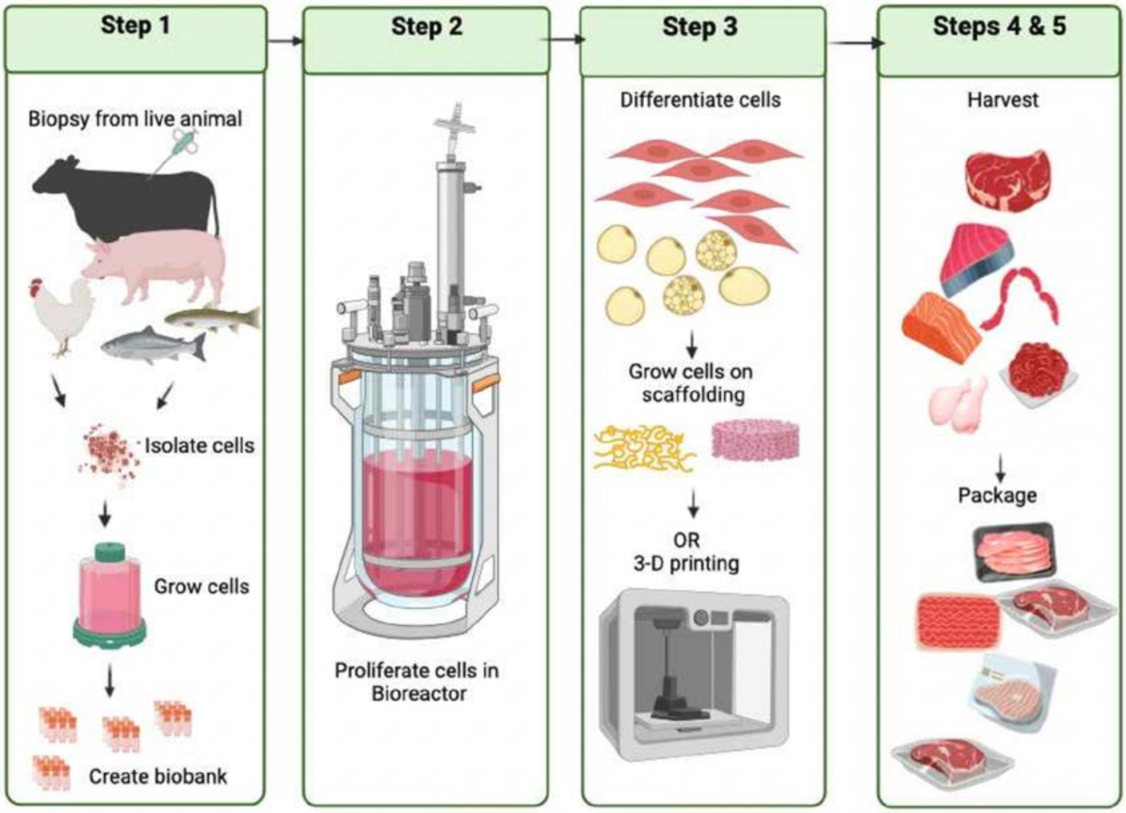

Figure 1 Production steps typically used in the manufacture of cultured meat.

assumptions for the model, they identified critical aspects of cultured meat production that need to be improved.[21] These areas are listed here to illustrate where much of the ongoing research in this field is focused: (1) facilities producing 10 000 metric tons of cultivated meat/year; (2) food-grade culture media made without animal products and hormones to enable cells to grow at high density and with cell doubling time of ~30 hours; (3) production cultivators with 10 000 L capacity; (4) differentiation to take place over a 10-day period in 2000 L perfusion cultivators; (5) overall continuous closed process without the use of antibiotics with minimum three harvests/run.

Progress is indeed being made towards these goals. Food-grade culture media,[22] the serum-free culture of meat[23] and an artificial version of fetal bovine serum have all been developed.[24] Cultured chicken products are currently on the market in Singapore.[25] In the USA, cultured chicken has been approved for consumption by both the Food and Drug Agency and United States Department of Agriculture.[26]

Health considerations of a vegetarian diet for young children

In adults, a vegetarian diet has been associated with a lower risk of chronic diseases and conditions such as high blood pressure,[27 28] coronary heart disease and type 2 diabetes,[29] weight control,[30] and improved gut health (including effects on the diversity of the microbiome and intestinal inflammation).[31] The American Academy of Pediatrics[32] and the Academy of Nutrition and Dietetics acknowledge that a well-planned vegetarian diet can meet the nutritional needs of young children.[33] However, the emphasis is on 'well planned', as children on vegetarian and vegan diets are at increased risk of deficiency in iron, B_{12} and calcium, and may have lower protein quality leading to amino acid deficits. Additionally, the health benefits of entirely plant-based diets in children under 5 years of age are less clear than they are in adults (see accompanying review article on vegetarian diets for children).[34] A recent systematic review concluded that, to date, there is no data demonstrating any health benefits of vegetarian diets in children aged 6 months to 2–3 years.[35]

Health effects of alternative meat for young children

As shown in table 1, there are multiple differences between the alternative meat products currently available and the traditional meat they are trying to replace. To date, there is no data available on health effects of specific types of alternative meat in young children and, given that most children will consume alternative meats as part of an omnivorous diet and that randomised trials in children are unlikely to be commissioned, evidence on health effects would likely be based on cross-sectional associations comparing high and low consumers. Specifically, the alternative meats are manufactured and typically contain higher levels of food additives which, although approved as safe, might have previously unknown harmful effects.[36 37] Meat alternatives typically offer the advantage of being lower in calories and fat. Several studies from

Table 1 Nutritional content of alternative meat products marketed in the USA in 2022

Product	Energy (kCal)	Serving size (g)	Total fat (g)	Saturated fat (g)	Trans fat (g)	Cholesterol (g)	Sodium (g)	Total carb (g)	Fibre (g)	Sugars (g)	Protein (g)	Iron (mg)	Calcium (%)	Vit A (%)	Vit C (%)
81% Lean angus ground beef patty	0.37	151	29	11	2	105	100	0	0	0	26	2.8	2	0	0
Beyond meat burger patty	0.29	113	22	7	0	0	340	4	1	0	18	3.7	6	0	0
Boca burger	0.12	70	4.5	1	0	<5	430	8	4	0	14	2.1	8	0	0
Dr Praeger's California veggie burger	0.12	71	5	0.5	0	0	240	14	4	1	5	1.1	4	25	8
Field roast burger	0.24	113	12	4	0	0	610	12	2	0	21	1.4	2	0	0
Gardein ultimate plant base	0.240	113	15	10	0	0	450	8	1	0	19	3.1	8	0	0

healthy adults have shown that replacing traditional meat with plant-based meat products can have a beneficial impact on markers of cardiac health and inflammation while having no detrimental effect on athletic performance,[38 39] but no such studies are available for children of any age on any cultured meat products.

Cultured meat

While the potential health benefits of cultured meat are promising, there are also concerns about the safety of these products, particularly for young children. The nutritional profile of cultured meat is generally similar to the meat from which the original cells are derived. A potential health benefit of cultured meat for children is that it could be manufactured to contain lower amounts of saturated fat and cholesterol and higher amounts of protein than traditional meat.[40] Additionally, it could be made to contain higher levels of specific nutrients, such as omega-3 fatty acids and vitamin B_{12}. Cultured meat could also be manufactured in the future free from pathogenic bacteria, such as *Escherichia coli* and Salmonella, that can often be found in traditional meat products.

One concern is the potential presence of harmful substances, such as antibiotics, hormones and environmental contaminants, in the cell culture medium used to grow the cells. While efforts are being made to develop more sustainable and safe cell culture methods, it is important to ensure that these products are rigorously tested and regulated before they are marketed to consumers.

CONCLUSIONS

Over the past 10 years, meat substitutes have gained significant attention as a sustainable and healthier alternative to traditional meat. Types of alternative meat include plant-based, mycoprotein-based, insect-based and cultured or cell-based products. Each type of alternative meat has its own advantages and challenges in terms of texture, flavour, nutritional value and consumer acceptance. In general, alternative meat products made from plants, mycoproteins or insects have a lower environmental impact and a beneficial impact on the health of adults in comparison to animal meat. Alternative meat should be included only as a very small part of the well-balanced diets of young children until more data is available.

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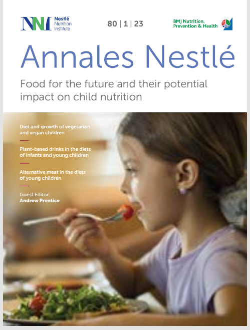

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