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Review

The Nutritional Quality of Plant-Based Foods

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Abstract: There is growing interest in the adoption of a more sustainable diet, and this has led to the development of plant-derived alternative products that are used as a substitute for products of animal origin. This is a promising way to improve the sustainability of the agricultural food industry; however, there are increasing concerns regarding the nutritional profile of plant-based products, with emerging evidence that many are not nutritionally equivalent to conventional animal products. In this study, we provide a narrative review focusing on the nutritional quality of plant-based alternative products. First, we summarize the available literature examining consumers' and healthcare professionals' perceived healthfulness and nutritional concerns regarding plant-based foods. Then, we compare the nutritional composition (macro- and micronutrients) of plant-based alternatives to their conventional animal counterparts. Moreover, we outline the potential impact of these nutritional differences on overall diet quality and provide a summary of the differences in the digestibility and bioavailability of nutrients from plant and animal sources. We highlight the role of product development and innovations in food processing to support the nutritional composition of plant-based products and outline the priorities for more comprehensive research on the nutrient density of these products and the sustained effect of modern plant-derived diets on long-term health.

Keywords: macronutrients; micronutrients; nutritional assessment; meat alternatives; vitamins

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Citation: Nolden, A.A.; Forde, C.G. The Nutritional Quality of Plant-Based Foods. *Sustainability* **2023**, *15*, 3324. https://doi.org/10.3390/su15043324

Academic Editors: Julia Low, Qian Yang and Lisa Newman

Received: 29 December 2022
Revised: 19 January 2023
Accepted: 24 January 2023
Published: 11 February 2023

1. Introduction

The primary motivation for the development of plant-based products is to provide consumers with tasty and nutritious alternatives to conventional animal products. This shift to plant-based alternatives has been motivated by a desire to reduce the environmental impact of food supply and improve the sustainability of agricultural food production. The plant-based sector has seen exponential sales growth and last year the US plant-based market was valued at $7.4 billion dollars [1] and estimated by Bloomberg Intelligence to reach $162 billion globally by 2030. While there is strong evidence to suggest that plant-based alternatives can have a significant positive influence on the environmental impact of food production [2,3], there are growing concerns regarding the nutritional profile of these products and their potential impact on overall diet quality [4]. Diet-wide changes to the foods we consume can profoundly influence the overall nutrient density and quality of the diet, and if sustained, promote the risk of diet-related chronic conditions. While dietary shifts have the potential to positively impact both health and sustainability, there is the concurrent risk that consumers conflate environmental benefits with improved health and nutrient density when these are independent product properties.

The terminology used to describe foods that do not contain animal proteins may be considered problematic, as the same term 'plant-based' has been used to describe vegetarian or vegetable-based options (e.g., veggie burger) but are not designed to "taste like meat" [5]. Here we consider the term 'plant-based' to refer to food products that do not contain ingredients of animal origin and are intended to mimic or replace conventional animal-based products (i.e., plant-based alternatives to meat, eggs, and dairy). Similarly, we acknowledge that plant-based diets often refer to 'flexitarian diets' that do not exclusively rely on plant-based products and the removal of all animal products.

From a product development standpoint, a top priority is recreating the textural and sensory experience of conventional animal products. This has proven to be challenging, as plant-based ingredients and proteins have a different sensory profile and physicochemical properties compared to animal-derived ingredients [6,7]. Advances are needed to improve both characteristics to continue to support the development of plant-based products that are indistinguishable from animal counterparts. Consumers value taste as the number one driver of food choice, followed by price, healthfulness, convenience, and environmental sustainability [8]. In a recent study specifically focused on plant-based foods, consumers prioritized taste, even if offered a tasteless and healthy product, noting that taste was important for food enjoyment [9]. Common strategies for improving the palatability of plant-based products include adding salt, sugar, and fat, which may have unintended consequences on the overall healthfulness of plant-based products. More evidence is needed as to whether these strategies improve the sensory attributes and overall acceptance of these products, as sensory studies are largely unsatisfactory within this product category (see reviews [10,11]).

Nutrient composition and product healthfulness are important factors for consumers when making food choices and there are growing concerns and rising confusion among consumers regarding the nutrient density and health benefits of plant-based foods. Several groups have raised concerns as to whether products are nutritious alternatives to traditional animal versions of the same foods [4,5,12,13]. We summarize consumer perceptions of the healthfulness of plant-based products and examine the nutrient composition, nutrient quality, and digestibility of modern plant-based products. Highlighting differences in nutrient quality and quantity can help emphasize the importance of products that have both improved sustainability and nutrient credentials and identify ways to educate consumers on how to make sustainable food choices that meet their dietary needs.

There is a rapidly growing body of literature examining the factors associated with the barriers to the adoption or willingness to try plant-based alternatives [12]. Consumer perceptions of plant-based foods are complex and are associated with both product-related factors (e.g., price, taste, convenience) and person-related factors (e.g., meat attachment, food neophobia, ethical values, etc.). The purpose of this review is to specifically focus on the consumer perceptions and actual comparison of the nutritional quality of plant-based foods, whereas other recent reviews have summarized the emerging evidence on consumer motivation to consume a plant-based diet [12,13].

The current review focuses on the nutritional quality of plant-based alternative products. First, we summarize the existing literature examining the perceived healthfulness and nutritional benefits and concerns of plant-based foods before comparing the nutritional composition (macro- and micronutrients) of plant-based alternatives to their conventional animal counterparts. Moreover, we outline the potential of these nutritional differences on overall diet quality and outline differences in the digestibility and bioavailability of nutrients from plant and animal sources. We highlight the role of food processing in supporting plant-based product development and offer future perspectives on the need for improved sensory appeal and nutrient density in plant-based products.

2. Consumer Perceptions of the Nutritional Quality of Plant-Based Foods

Many healthcare professionals report confusion among consumers regarding the nutritional differences between plant-based and conventional animal products [5,14]. From a nutritionist's perspective, many plant-based alternatives lack nutrients such as iron, vitamin D, and B12, may have lower levels or quality of protein, and often have higher sodium and fat contents compared to traditional animal products [5,14]. Consumers often report a lack of understanding in relation to the nutrient differences between plant- and animal-based versions of products such as milk, meat, and eggs. Previous findings report that two-thirds of consumers believe health is the primary motivation for their dietary choices [5] and many flexitarian consumers perceive plant-based products to be healthier than conventional animal products [15–17]. Conversely, others report that consumers have concerns regarding the macro- and micronutrient content of plant-based foods and the presence of many unfamiliar ingredients [18]. When asking consumers to select the healthier option between two nutrition facts panels, 45% of participants selected the plant-based beef alternative to be healthier than the beef option, which decreased to 40% after showing the ingredient list [18]. Over half of the consumers surveyed (56.4%) agreed that consuming a plant-based diet promotes good nutrition [5], yet it remains unclear how well consumers understand the nutrition facts panel or ingredient statement or whether they utilize this information when making their food choices. These data suggest that perceived healthiness and nutritional quality are important factors driving consumer acceptance of plant-based foods. Further research is needed to understand the alignment between consumers' perceived health benefits of consuming a plant-based diet and the nutrient quality of many emerging plant-based foods.

3. Comparison of Nutrients between Animal- and Plant-Based Foods

We summarize some of the known advantages and potential disadvantages of switching from animal to plant-based products from a nutritional perspective, focusing on differences that have appeared in the literature across product categories (Figure 1).

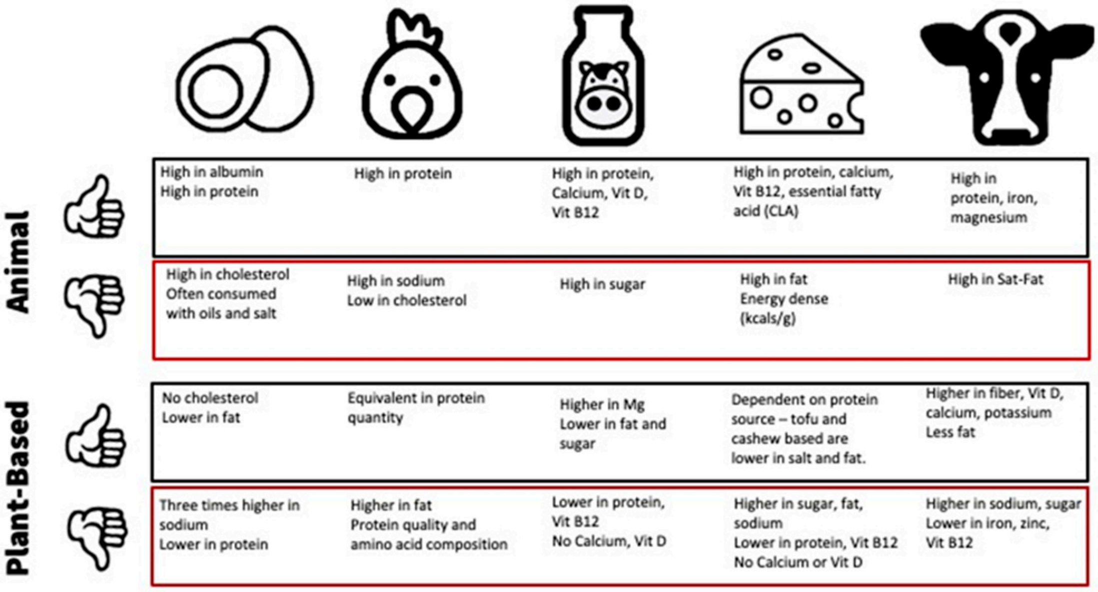

Figure 1. Summary of the key nutrient differences between animal- and plant-based products. These are generalized statements based on findings within each product category, with large differences observed, driven by the plant-protein source, and added ingredients. This figure incorporates findings previously reported [19–30].

3.1. Macronutrients

Animal products, such as meat, eggs, or dairy, are broadly consistent in nutrient composition across different product categories and regions. Conversely, there is a much wider variability in nutritional composition among plant-based ingredients depending on their source (e.g., soy, oat, coconut), variety, and geographical location. Furthermore, even within plant-based foods, there can be wide variability between different forms of the same ingredient, such as flour, concentrates, and isolates [6]. For example, within chickpeas, the percentage of protein content can vary considerably across different protein forms, from 20% in flour to 98% in concentrate. Similarly, for lentils, protein content is only 27% in flour and 91% in lentil protein concentrate [6]. In addition to variability in protein content, other macro- and micronutrients vary considerably, including fiber, vitamin, and mineral content of these ingredients. Such diversity in nutrient composition adds significant complexity for consumers who intend to switch to plant-based animal alternatives for environmental reasons while still striving to balance their nutrient requirements. The protein content of plant ingredients offers wide versatility and may afford economic and environmental advantages. However, differences in the composition of a raw material pose significant challenges when formulating products to mimic the nutrient and sensory properties of animal proteins. Plant proteins require additional formulation to remove anti-nutritional components and enhance digestibility and nutrient density, taste, and functional properties (e.g., water and oil holding capacity) from different plant sources. Plant-based foods are naturally lower in fat and cholesterol and higher in fiber content than foods of animal origin. However, many modern formulated plant-based products contain higher amounts of salt, fat, and sugar which are often added to mask the unattractive taste or texture qualities inherent to plant protein or to aid in mimicking the sensory properties of animal-based products.

Plant-based animal product alternatives offer several advantages in terms of their nutritional qualities compared to conventional animal-based products. Several studies have compared plant- and animal-based products across several categories, including meat analogs [19–23], yogurt [24], milk [24–27], and cheese [19,20,24,27–29]. It is important to note that nutrient differences are dependent on the product category being compared, as each conventional animal product offers specific nutrient benefits. For example, dairy offers a rich source of protein, vitamin D, and calcium, while cheese is a source of calcium, fat, and protein. Conversely, regular consumption of beef has been associated with higher cardio-metabolic and cancer risk and is a source of saturated fat, cholesterol, and sodium.

Consumers may look to plant-based meat alternatives to meet the sensory appeal of traditional animal products, yet may be surprised to learn the degree to which these products differ in their nutrient content in often unseen ways. Plant products are higher in fiber and lower in fat compared to animal products [20–22,24], although these differences vary between product categories (see Figure 1). Though true for many categories, plant-based yogurt contains more total and saturated fat than conventional dairy yogurt since plant-based yogurts are often produced with coconut or nuts to enhance mouthfeel and flavor retention, which contributes to the higher fat content [24]. Some plant-based milks, such as those made from coconut, can contain more fat than whole milk yogurt [24,26]. In cheese, there are large differences in the nutritional profile across different types of cheese, but significant differences were observed for some cheese types, with significantly higher levels of saturated fat [19,24]. Coconut and nuts naturally contain fat but offer taste and texture attributes that are more desirable than other pulse-derived plant proteins, delivering a comparable profile to conventional animal products. A comparison of plant-based protein ingredients in these products provides insight into their contribution to the fat content, with coconuts and nuts containing more fat compared to peas, whey, and soy [24].

Several studies report that plant-based products contain significantly less protein [19,21,23,24,26,28]. For example, when comparing a burger patty, plant-based burgers provide less protein for equivalent calories compared to beef burgers (18 g compared to 24 g, respectively) [21]. In line with this, plant-based yogurt provides, on average, 1.6 g protein per 100 mL serving, compared to 3.3 g protein in cow's yogurt [26]. This was also observed for plant-based cheeses [20,24], with dairy cheese providing 16 g whereas plant-based cheese provided 6 g (per 100 g) [24]. Animal foods are seen as a source of protein, and current plant-based foods may not provide equivalent amounts of protein when substituted for conventional animal-based products.

From a product development perspective, sugar and sodium play an important role in the physicochemical properties of plant-based foods and can provide desirable sensory and mouthfeel characteristics. An emerging concern for plant-based meat alternatives is their higher sugar and salt content. Higher fat and salt content is often observed after cooking, as many newer formats of plant-based products undergo frying in oil and are heavily seasoned with salt before consumption to enhance their sensory appeal [30]. Current estimates are that plant-based burgers contain up to twice as much sodium as beef burgers [21]. Plant-based yogurts (coconut, nut, and soy-based) contain significantly more salt (~0.2 g/100 g) compared to dairy-based yogurt (0.16 g/100 g) [24]. Alternatively, others reported no difference in sodium content in plant-based milk [19,24] and plant-based meat [19]. There is less evidence that plant-based products contain concerning amounts of sugars. Studies examining plant-based meat failed to find differences in sugar content with animal-based meat [20,21]. Similarly, plant-based dairy (milks, yogurt, and cheese) contains the same or fewer sugars, including those made with coconut, grains, nuts, and seeds [19,24].

There are several examples of plant-based products offering fewer calories than equivalent animal products. For example, cow's milk provides 50 kcal (per 100 mL), compared to coconut (33 kcal)- and grain (48 kcal)-based dairy [24]. Lower energy was also observed for plant-based meat products (201 kcal) and burgers (183 kcal) available in the Norwegian market, compared to animal meat (224 kcal) and beef burgers (225 kcal) [19]. This is consistent with plant-based burgers in the US market [21]. Conversely, one study examining plant-based meat products available in the Swedish market found no differences in the nutritional contribution of energy on a kcal/100 g basis between plant-based and animal-based products [22]. The variability in findings across studies could also be the result of different analytical approaches.

Many plant-based products are positioned as higher in protein content, but the digestibility of plant-based foods can differ considerably [31]. Moreover, many plant-protein products can have surprisingly high levels of fat or salt as producers formulate for sensory appeal without the use of animal-derived ingredients. This can result in higher intakes of saturated fat, salt, or sugar. For consumers, these differences in nutrient intakes become all the more challenging to manage with the added complexity of diverse and inconsistent sources of plant-based foods, which in turn can directly impact the nutrient profile of formulated products in the plant-based category. In the absence of clear and specific information or uniformity of nutrient density across the many rapidly emerging and diverse plant-based product categories, the challenge remains for consumers to inform, guide, and select plant-based products that meet their nutritional needs.

3.2. Micronutrients

As with variability in macronutrients, there is also wide variability across plant-based product categories in terms of their vitamin and mineral contents. Many vitamins, minerals, and amino acids are only found in animal products, such as taurine, Vitamins B12, and D3, iron, and essential fatty acids, such as docosahexaenoic acid [23,32]. Conversely, many plant foods can provide micronutrients not found in meat, such as vitamin C and antioxidants only found in plants, such as flavonoids (quercetin, catechins) [33]. While these additional micronutrients can provide advantages, consumers making the transition to a plant-based diet often look to the same foods for their micronutrients and are poorly prepared for a lower nutrient density or missing nutrients compared to their traditional animal-based diet. For example, beef products contain Vitamin B12, iron, magnesium, and zinc, which are less abundant or non-existent in many plant foods [23,24]. For plant-based dairy alternatives, there are concerns regarding calcium and potassium [24]. Recently, producers of plant-based meat alternatives have begun fortifying their plant-based products with added vitamins and minerals in an effort to mimic the micronutrient profiles of conventional animal products. A recent comparison of 27 different plant-based milks showed they were lower than conventional milk for fat, carbohydrates, vitamins C, B2, B12, and A, biotin, pantothenic acid, calcium, phosphorus, and iodine [34]. Not all plant-based milks are the same. Soy milk has higher protein, vitamins B1, B6, and E, folic acid, and added D_2 and K, magnesium, manganese, iron, and copper than cow's milk or other plant-based milks. Results highlight that plant-based milks are not comparable to cow's milk in nutrient composition, even when fortified.

To demonstrate the differences between plant and animal products, we compared the vitamin and mineral content of plant-based and animal-based beef burger patties. For burgers, on a per-serving basis, those prepared with plant proteins provided more vitamin D, calcium, and potassium, with no differences in vitamin C and A content, compared to beef burgers [21]. For ground meat, on a standard three ounce basis, plant-based products provided a good or high source of iron, manganese, copper, folate, and niacin but provided less zinc and vitamin B12 compared to ground beef [23].

In addition to the sustainability credentials of animal-free meat, plant-based products offer a novel opportunity to enhance the nutrient quality of products by providing vitamins and minerals not traditionally found in animal-based products. However, at a minimum, consumers expect these products to provide a similar nutrient density as conventional animal products. This will continue to be a challenge for plant-based product developers as many micronutrients are not present in high quantities in plant foods. Whereas plant-based options are often nutritious, they are not equivalent in their nutrient profile or density to animal-based products. One approach to compromising these expectations is through combining animal and plant ingredients, resulting in blended or 'hybrid' products. These products help to reduce meat consumption, substituting a portion of animal protein with plant-derived proteins. Future hybrid or blended products may offer a solution by reducing rather than removing all traces of animal ingredients from the final product, and through this, decreasing the environmental impact associated with animal food products while retaining an optimum nutrient profile.

The essential amino acid content of a plant-based protein is also critical to consider, as this can directly impact the potential of a protein to support muscle accretion and anabolic activity. When a protein source is missing one or more of the essential amino acids, evidence suggests the remaining acids are oxidized rather than used to support anabolic activity in the muscle [35]. To date, long-term studies to assess the effect of shifting to a plant-based vegan diet matched to the protein content of a traditional animal-based diet have not been completed. Metabolomic profiles of traditional meat products may vary from plant-based meat, with greater diversity in the metabolite profile following consumption of ground beef compared to an equivalent serving of plant-based meat [33]. Large differences were observed for vitamins, amino acids, phenols, tocopherols, and fatty acids, having a potential effect on physiological, anti-inflammatory, and immunomodulatory implications, factors not considered when examining nutritional facts panels [33].

There remains a shortage of long-term clinical evidence on the health effects of substituting animal-based foods for newer plant-based meat, dairy, and eggs. Results from two randomized controlled trials have shown mixed benefits, with one showing a beneficial reduction in low-density lipoprotein (LDL) cholesterol [36], whereas another showed a potential negative effect of plant-based diets on bone health [36]. For consumers, it is important to consider subtle differences in the quantity and diversity of components that are often not listed on a nutrition facts label, including the levels of amino acids, saccharides, phytosterols, tocopherols, and antioxidants, when evaluating a product, the holistic nutrient quality, beyond product macronutrient and energy content. Replacement of conventional animal-based products with plant-based alternatives is likely to lead to deficiencies for certain important nutrients in the longer term unless accompanied by dietary adjustments.

4. Whole Diet Comparisons and Concerns about the Digestibility of Plant-Proteins

4.1. Comparison of Diets

Whereas nutritional comparisons between plant and animal-based versions of the same product provide an important appraisal of the nutrient impact of specific product switches, they provide little information on how these products contribute to a complete diet. Currently, there is limited longitudinal data on the nutrient impact of consuming diets containing novel plant-based food products, such as PMBAs, nut milk, or vegan eggs, compared to a traditional animal-based diet [30]. Previous research has shown that reducing or replacing animal protein intake with plant proteins is associated with a lower risk of death [37] and a lower risk of death due to cardiovascular disease [38,39]. A short-term dietary intervention study that included a focus on a plant-based diet, along with lifestyle modifications, resulted in improved body mass index and LDL cholesterol levels [40]. These studies focused on protein-rich plant foods, such as pulses, beans, and tofu, or self-reported diet type (i.e., vegan, vegetarian, etc.) rather than newer alternative plant-based products such as plant-based meat alternatives. Moreover, replacing some animal products with plant foods poses concerns for not meeting recommended daily amounts of calcium and vitamin D, which can negatively impact bone health [41]. In a comparative diet quality study, a diet consisting of novel plant-based foods provided more saturated fat, sodium, and sugar, above the traditional reference diet, and did not meet the recommended daily allowance for vitamin B12, calcium, potassium, magnesium, and zinc [4]. Tonheim and colleagues (2022) report that when comparing the nutritional composition of plant-based diets (vegan, vegetarian, and pescatarian), there were differences in consumption of alternative products, with vegans consuming more products than vegetarians and pescatarians [42]. Individuals consuming plant-based alternatives to animal products had a greater intake of saturated fat and protein. Animal substitutes did not contribute to differences in the intake of carbohydrates, added sugar, or dietary fiber compared to other diets.

Many of the established health benefits of a traditional vegan or vegetarian diet, compared to the omnivore diet, have been appropriated to support claims made about the putative health benefits of consuming many newer plant-based meat and dairy alternatives [30]. Whereas traditional vegan and vegetarian diets were high in vegetables, nuts, and pulses, much of the popularity surrounding more novel plant-based foods has arisen from their positioning in 'fast-food' formats (i.e., burger, sausage, nuggets) that usually requires the addition of salt, sugar, and fat to promote their sensory appeal. In addition, many of these products have long ingredient lists and have been characterized by some as highly or 'ultra' processed foods [43]. This is achieved through combinations of protein isolates, bulking and stabilizing agents, and a host of flavor additives and enhancers to recreate the desirable sensory and mouthfeel of animal products. As such, it cannot be assumed that these products are nutritionally comparable to traditional vegetarian or vegan plant-based diets. For many consumers, the message that vegetarian diets are healthier can easily be extended to their perception of these novel formulated product formats and may mislead them to switch to products that are perceived as healthier, though they are frequently nutritionally inferior to meat and traditional vegetarian diets.

4.2. Digestibility and Bioavailability

The nutrient composition of a food product describes it's composition in terms of macro- and micronutrients and energy content; it does not truly reflect what is absorbed or the true metabolic impact of its consumption [44]. Bioavailability can influence the nutritional quality of a food and the subsequent metabolic impact of its consumption. As such, foods with identical nutrient compositions can differ in functionality and have a distinct metabolic and physiological impact on consumption. Plant-based products differ from conventional animal products in their composition, structure, and functional properties. Compared to animal protein, plants, including plant-based ingredients and plant-based proteins, have lower bio-accessibility and bioavailability. For plant-based foods, there are concerns about the bioavailability of these products for vitamins and minerals, including calcium, iron, and zinc, among other vitamins and minerals. There is currently limited clinical research in human populations that explores the bioavailability of vitamins and minerals when incorporated into novel plant-based food matrices designed to resemble meat or dairy products. Both plant protein and cereals contain phytic acid, often described as an antinutrient, that can inhibit the absorption of iron, zinc, calcium, and manganese [45]. Other components in animal-alternative foods can also reduce or prevent the absorption of important nutrients. A recent randomized controlled trial compared iron absorption from animal protein and edible insects [46]. Results showed that iron absorption from edible crickets and maize flour enhanced with crickets is low, with in vitro digestion suggesting this is likely due to the high chitin content in the cricket's biomass.

In general, all plant-based ingredients have a lower bioavailability as they contain a food matrix that presents a physical barrier to digestive agents (e.g., dietary fiber) along with other barriers, including antinutrients [45]. Structurally, a plant's food matrix is more complex than animal matrices, reducing the accessibility of nutrients during digestion. For example, plants have higher dietary fiber, which is described to be resistant to digestive enzymes in the small intestine [47]. However, this effect appears to depend on molecular weight and degree of esterification. Whereas consumption of increased quantities of dietary fiber can have positive health benefits, this natural barrier may also reduce the bioavailability of plant-based foods. While the majority of attention has focused on matching the protein content of plant-based food to that of meat and dairy, protein quality and digestibility have received less attention. Plant-protein quality is determined by its essential amino acid content, its digestibility, and the bioavailability of the digested amino acids [31]. Animal meat has more bioactive peptides and higher protein digestibility compared to plant-based meat alternatives [48,49]. To compare protein quality, the Food and Agricultural Organization (FAO) uses a scoring system that assesses protein quality across a diverse range of metrics. The Digestible Indispensable Amino Acid Score (DIAAS) assesses the protein quality by considering the bioavailability and concentration of each amino acid. There are some concerns about this approach as it may not account for differences in food matrix integrity across protein sources (e.g., pea protein isolate compared to eggs) [50]. The estimated bioavailability of protein from plant sources is lower (89–92%) compared to meat and milk proteins (90–95%) [51]. Overall, there is limited knowledge of the gastrointestinal differences between animal and plant-derived products [52].

Plant-based dairy alternatives often have lower protein and nutrient contents and differ widely in the bioavailability observed across different nut and seed milk alternatives (e.g., soy, nut, seeds) [24,26,53]. These differences in calcium bioavailability are driven by the profile of antinutrients (i.e., tannins, phytic acid, saponin, etc.) across plant-based sources. Processing of these products can help to increase the bioavailability of vitamins and minerals (e.g., thermal applications, mechanical processing, soaking, fermentation) by degrading or altering the antinutrients, but may also have an unintended impact on the sensory properties and consumer (e.g., taste, texture) [45,54]. These differences in bioavailability are not fully understood but can be estimated by examining the dietary quality and nutritional outcomes in humans with diet types. Desmond and colleagues (2021) recently reported that children (5 to 10 years old) consuming a vegan diet had an increased risk of nutritional deficiencies and lower bone mineral content, and were shorter compared to those consuming an omnivorous diet [55]. This is one example that suggests that diets lacking animal products can have long-term effects. This study did not examine the consumption of alternative products but suggests that diets consisting of only plants can lead to nutritional and health concerns.

5. Innovations in Processing and Strategies for Increasing Nutritional Quality

5.1. Strategies and Processing Techniques to Improve the Nutritional Quality

Recent innovations and advances in technologies are striving to make healthier plant-based proteins including nanoencapsulation [56] and fermentation [57,58]. In addition to improving the nutritional profile, these strategies may also improve the sensory profile. For example, the fermentation of plant-based yogurt has been thought to increase acceptance and deliver a desirable mouthfeel [59]. There is an opportunity for plant-based products to deliver further health benefits. For example, plant-based dairy products offer a suitable vehicle to deliver probiotics [60].

5.2. Consumer Concerns Regarding the Processed Nature of Plant-Based Foods

Consumers' motivation to include more plant-based foods in their diets is driven by a wider concern for the environment and animal welfare and the desire to 'simplify' dietary intakes through the removal of highly processed foods. This is an extension of the consumer macro-trend for 'clean label' products motivated by the appeal of consuming more natural foods with fewer additives, an intrinsic perception that clean label is healthier, and a desire to move away from industrialized food production [61]. Whereas many consumers may conceptualize processed foods as 'unhealthy' they are also willing to embrace novel formulated plant-based meat alternative products which utilize highly processed plant-protein isolates and concentrates. This apparent contradiction is largely due to the health halo surrounding many novel plant-based meat alternatives, where increased sustainability is conflated with improved health and naturalness credentials. A recent analysis of vegetarian and vegan diets highlighted that this population often showed increased consumption of plant-based foods that are classified as 'ultra-processed' based on the NOVA scheme [62]. While more studies are needed, preliminary studies suggest consumers may consider plant-based foods as undesirable due to their processing and 'unnaturalness' [43]. Consumer rejection of foods based on their degree of processing represents a barrier to innovations in food technology and formulation to be applied to enhance the healthfulness and sensory appeal of plant-based foods [63]. From a nutritional perspective, whether a food is processed to enhance its convenience, shelf-life, or sensory appeal does not automatically preclude it from being nutritionally balanced or healthy. Importantly, if populations around the world are to make the urgent changes needed in food production and consumption habits in an effort to reduce the impact of global warming, then advanced food technology, preservation, and processing will be required to reduce food loss through inefficiencies, currently estimated to be up to one-third of all food produced. In this regard, consumers may need to further embrace and accept novel technologies for convenience, taste, and cost when making the transition to a largely plant-based diet [63].

Appealing plant-protein products are not a recent creation, with products such as tofu and seitan dating back hundreds of years. The more recent development of novel plant-based meat-alternative products can offer consumers a wide selection of convenient ways to substitute animal products for products that provide similar functions and taste. However, this is not the only way for consumers to reduce their meat consumption or derive the health benefits long-established from consuming a more plant-based diet. It is also possible to reduce meat and dairy intake without replacing this with modern plant-based alternative products and instead to cut consumption or increase intakes of fruits, vegetables, and pulses. Plant-based products that are positioned to replicate the sensory experience of meat or dairy have been widely reported to not meet consumer expectations for their taste and texture. In an effort to meet these expectations, producers often rely on the addition of fat, sugar, salt, and cosmetic flavor enhancement to mask undesirable side tastes associated with plant-based foods (i.e., the beany-off tastes of lentils and pulses). Consumers are increasingly aware of the nutritional content of emerging plant-based foods and in the future are likely to be less concerned about the manner in which their foods are processed (i.e., heating, dehydration, freezing, etc.) and more concerned with balancing the drive for more sustainable eating habits with the health and sensory pleasure that can be derived from plant-based foods.

6. Conclusions and Future Outlook

The current chapter highlights many of the differences in nutrient composition and bioavailability between plant and animal foods. For many consumers, the message that vegetarian diets are healthier can easily be extended to novel formulated product formats. It may mislead them to switch to products that are perceived as healthier [18], though they are frequently nutritionally inferior to conventional animal products [23,26,28,33]. These differences in consumer perception of plant-based foods highlight the confusion surrounding their nutritional quality and reflect the poor understanding of the nutrient implications of substituting products of animal origin with plant-based alternatives [30]. For consumers, these differences in nutrient intakes become complex to manage with the wide diversity in composition and added variety of emerging plant-based alternatives. It is important to consider subtle variability in the quantity and diversity of components that are often not listed on a nutrition facts label, including the levels of amino acids, saccharides, phytosterols, tocopherols, and antioxidants when evaluating the holistic nutrient quality of a product, beyond product macronutrient and energy content. This diversity in composition becomes even more complex when differences in the digestibility and bioavailability of nutrients of plant origin are also considered. In the absence of clear and specific information or uniformity of nutrient density across the many rapidly evolving and diverse plant-based product categories, the challenge remains for consumers to inform themselves and select plant-based products that meet their nutritional needs. Considerations should be made on education and labeling of products to help consumers when it comes to selecting the right plant-based alternative product based on their individual needs and expectations.

Whereas substituting plant-based alternative products for products of animal origin from the diets may be effective from a sustainability standpoint, from a nutritional standpoint, it may be wise to consider a partial substitution or replacement with plant foods rather than removing all products of animal origin from our diets to sustain nutrient intake and maintain health. For example, previous research has shown that retaining dairy and eggs with a smaller proportion of meat successfully maintained protein and micronutrient intake while supporting a more sustainable eating pattern [4]. Another approach that is gaining popularity are blended or 'hybrid' products. These products help to reduce meat consumption, substituting a portion of animal protein with plant-derived proteins. Future hybrid or blended products may offer a solution by reducing rather than removing all traces of animal ingredients from the final product, decreasing the environmental impact associated with animal food products while retaining an optimum nutrient profile. The more recent development of novel plant-based meat alternative products offers a wide selection of convenient ways to substitute animal products for products that provide similar functions and taste. However, this is not the only way consumers can reduce their meat consumption or derive the long-established health benefits of consuming more plants. Consumers remain free to reduce their meat and dairy intake without replacing this with modern plant-based alternative products and instead increase their intake of fruits, vegetables, and pulses.

It is important to note that the nutritional comparisons in the current review are not without limitations. Not all nutritional analyses are conducted in a standardized way across studies, with differences in controlling for serving size (e.g., one burger patty vs. 100 g) and reported nutrients. Additionally, recommended daily values are different across countries. To build on the existing research, future studies should consider reporting actual values rather than daily values, which will support developing a scientific framework that is relevant across countries.

Future research requires detailed dietary assessment and controlled clinical trials to fully understand the nutrient implications of switching to diets dominated by plant-based alternatives that mimic animal products. There is a need to evaluate the longitudinal effects of shifting to diets consisting of plant-based alternatives and assess health outcomes in vulnerable populations and compare metabolic biomarkers and the potential impact on the gut microbiome to fully understand the implications of these dietary changes on long-term human health. This is further complicated by the rate of change in newer products and novel plant-based foods that continue to evolve and improve rapidly. Many of the established health benefits of a traditional vegan or vegetarian diet compared with the omnivore diet have been appropriated to support health claims made about the effect of consuming novel plant-based alternatives [4,30]. Whereas traditional vegan and vegetarian diets were high in vegetables, nuts, and pulses, much of the popularity surrounding more novel plant-based foods has arisen from their positioning in 'fast-food' formats (i.e., burger, sausage, nuggets) that usually requires the addition of public health sensitive ingredients high in salt, sugar, and fat to promote their sensory appeal. The current diversity within the emerging plant-based category, combined with the lack of long-term evidence on the efficacy of these products to support adequate nutrient intakes, suggests caution should be exercised when transitioning to a plant-based diet using novel plant-based products as many cannot be considered equivalent to traditional animal-based products [4].

As the popularity of flexitarian and plant-based diets continues to rise, there are unique opportunities to shift consumer behavior towards dietary patterns that are not only more sustainable, but also healthier. To capture this opportunity and galvanize consumer motivation for dietary change, the responsibility now falls on product developers to optimize not just the sensory appeal and format but also the nutrient density of this emerging category of foods. Further research on the nutritional impact of shifting to modern plant-based foods is now needed to provide the evidence base to direct consumer choices towards the healthiest and most sustainable versions of the next-generation products. In parallel, there is a need for greater consistency in the nutrient content of new product formats that sustain sensory appeal without the need for added frying or condiments that contribute to salt, sugar, and fat intake, if we are to avoid an unintended decline in diet quality.

Author Contributions: Conceptualization: C.G.F.; collection and review of the literature: A.A.N. and C.G.F.; writing of the manuscript: A.A.N. and C.G.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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