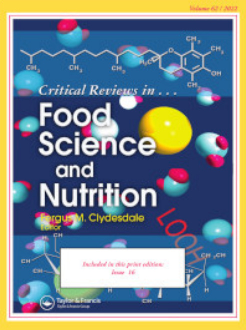
Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception

Kandi Sridhar, Said Bouhallab, Thomas Croguennec, Denis Renard, Valérie Lechevalier-Datin



Taylor & Francis
Taylor & Francis Group

Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception

Kandi Sridhar, Saïd Bouhallab, Thomas Croguennec, Denis Renard & Valérie Lechevalier

To cite this article: Kandi Sridhar, Saïd Bouhallab, Thomas Croguennec, Denis Renard & Valérie Lechevalier (2022): Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2022.2081666

To link to this article: https://doi.org/10.1080/10408398.2022.2081666

Published online: 01 Jun 2022.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2022.2081666

Taylor & Francis
Taylor & Francis Group

REVIEW

Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception

Kandi Sridhar[a], Saïd Bouhallab[a], Thomas Croguennec[a], Denis Renard[b], and Valérie Lechevalier[a]

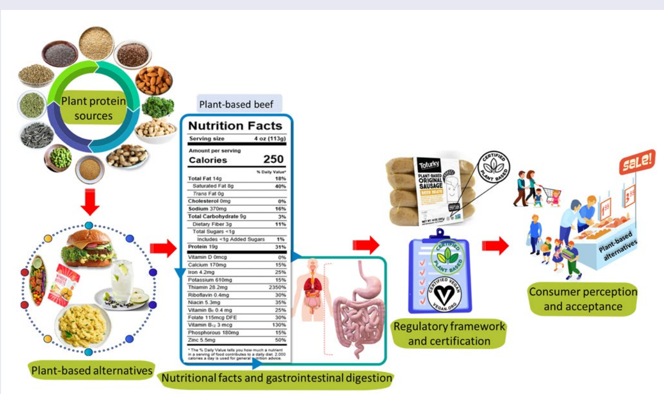
[a]INRAE, Institut Agro Rennes-Angers, STLO, Rennes, France; [b]INRAE UR 1268 Biopolymères Interactions Assemblages, Nantes, France

ABSTRACT

In recent years, various types of plant-based meat, dairy, and seafood alternatives merged in the health-conscious consumer market. However, plant-based alternatives present complexity in terms of nutritional profile and absorption of nutrients after food ingestion. Thus, this review summarizes current strategies of plant-based alternatives and their nutritional analysis along with gastrointestinal digestion and bioavailability. Additionally, regulatory frameworks, labeling claims, and consumer perception of plant-based alternatives are discussed thoroughly with a focus on status and future prospects. Plant-based alternatives become a mainstream of many food-processing industries with increasing alternative plant-based food manufacturing industries around the world. Novel food processing technologies could enable the improving of the taste of plant-based foods. However, it is still a technical challenge in production of plant-based alternatives with authentic meaty flavor. *In vitro* gastrointestinal digestion studies revealed differences in the digestion and absorption of plant-based alternatives and animal-based foods due to their protein type, structure, composition, anti-nutritional factors, fibers, and polysaccharides. Overall, plant-based alternatives may facilitate the replacement of animal-based foods; however, improvements in nutritional profile and *in vitro* digestion should be addressed by application of novel processing technologies and food fortification. The specific legislation standards should be necessary to avoid consumer misleading of plant-based alternatives.

KEYWORDS
Plant-based alternatives; nutritional analysis; *in vitro* digestion and bioavailability; labeling claims; consumer perception

GRAPHICAL ABSTRACT



Introduction

Over the years, the world population of 7.60 billion is expected to reach 8.60 to 11.20 billion by 2050 to 2100 (UN 2017). Moreover, urbanization of 49% is foreseen to reach 70% of global population by 2050 due to increased economically wealthier population. This in turn impacts the ratio of food producers to food consumers, food production process, and food security. Thus, there is a shortfall between the food production and the amount needed to feed the population by 2050. According to a projected meta-analysis, a 70% increase in global food production should be needed by 2050 with an improved nutritional diet and reduced climate impacts (van Dijk et al. 2021). However, animal-based food production resulted in an unsustainable food system with 14.5% of anthropogenic greenhouse gas (GHG) emission and high agricultural land use (Hadi and Brightwell 2021). This has become one of the great challenges of the coming years: to sustainably feed 10 billion people by 2050 with a healthy and balanced diet. Thus, the concept of switching to a plant-based diets as an attempt to substitute conventional animal-based diets arises to protect the environmental footprints and to develop a more sustainable food supply.

Plant-based diets are originated from plant sources (e.g., cereals, legumes, nuts, fruits, and cooked/raw

CONTACT Valérie Lechevalier valerie.lechevalier@agrocampus-ouest.fr

vegetables) to maximize consumption of nutrient-dense plant foods that can mimic conventional animal-based foods, including dairy products, eggs, and other animal processed foods (McClements 2020). Due to health and environmental concerns, many consumers significantly shifted their interest in a wider variety of plant-based foods that could offer all required nutritional benefits. Many consumer-centric fast-food and breakfast restaurants embrace a plant-forward eating approach to meet the consumer demand. For instance, a survey conducted by Technomic® documented that 41% of millennials and Gen Z enjoy adopting new plant-based foods and beverages at restaurants (Technomic 2020). Moreover, plant-based diets are important to maintain a healthy immune system and to protect against many respiratory tract illnesses (e.g. coronavirus disease 2019) and overall health (Kim et al. 2021). Among the plant-based diets, plant-based protein rich diets/plant-based alternatives are of immense importance and have the ability to meet the growing demand for protein from non-meat sources. Although plant-based alternatives may not offer the same nutritional benefits as animal-based foods, recent advances in food fortification and microencapsulation improved the nutritional profile of plant-based alternatives to meet protein quality similar to animal proteins (Clegg et al. 2021). Recently, Kerry Group launched ProDiem™ Refresh Soy for clean-label, more sustainable, and optimized nutritional profile to meet protein quality similar to milk or egg proteins (Kerry 2020). Similarly, McClements (2020) compared the nutritional profile of plant-based burger (Impossible Whopper™) and conventional beef burger (Whopper™). The plant-based burger reported to have less calories, fat, and cholesterol, while more carbohydrates, sugar, and salt than the beef burger. However, the protein content was found to be almost equal in both burgers. Thus, the growing sense of plant-based alternatives skyrocketed with a wide variety of new products, such as meat, dairy, and seafood alternatives formulated with various plant-based proteins, legumes, nuts, and oils that can mimic the similar taste and functions as traditional animal-based foods.

To date, a considerable amount of literature has been published for the formulation and practice of plant-based alternatives for better health and to protect the environment (Kerry 2020; Krause and Williams 2019 May-Jun; Lacour et al. 2018; McClements 2020). Nevertheless, this concept has recently been challenged for their nutritional profile and the absorption of nutrients after food ingestion. Recently, few reviews and studies have heightened the development of plant-based alternatives (to meat, dairy, and seafood) emphasizing on production process and consumer acceptance (He et al. 2020; Kazir and Livney 2021; Pointke and Pawelzik 2022; Santo et al. 2020; Sethi, Tyagi, and Anurag 2016; Zhang et al. 2021). However, systematic overview on plant-based meat, dairy, and seafood alternatives, as well as their nutritional information, gastrointestinal digestion, and labeling regulations would provide a full-fledged scenario of plant-based alternatives and their bevy of potential health benefits. Therefore, an evidence focus on these aspects should open-up barriers to increase scientific knowledge and understanding of adopting plant-based alternatives for a healthier and more sustainable food supply.

Hence, this review article summarizes current strategies of plant-based alternatives (to meat, dairy, and seafood) and their nutritional analysis along with gastrointestinal digestion and bioavailability. Moreover, various regulatory frameworks, labeling claims, and consumer perception of plant-based alternatives are discussed thoroughly with a focus on status and future prospects.

The blooming plant-based food industry

The current transition of adapting more plant-based alternatives has been a systematic strategy for more sustainable patterns of food production and consumption. In response to the call of sustainable food systems, plant-based alternatives are gaining traction and will continue to evoke interest with a wider variety of plant-based ingredients in the consumer market. Moreover, changes in consumer lifestyle, desire for clean-label, allergy-free, balanced way of eating, and ease of digestion are fueling the global plant-based market. According to a recent survey, the value of global plant-based alternatives was USD 29 billion in 2020, which is expected to hit USD 162 billion by 2030, underlying the market space for plant-based alternatives in the food manufacturing industry (Bloomberg-Intelligence 2021). The global plant-based industry is mainly categorized into plant-based meat, dairy, and seafood products. The sales of plant-based meat alternatives are a rapidly-growing category with a worth of USD 1.4 billion, which was drastically increased by >430 million from 2019 to 2020 and may reach USD 118 billion over the next 10 years (Figure 1A). Likewise, the plant-based milk alternatives are the most developed plant-based category, representing 35% of the total plant-based food market (GFISM 2021a). The rapid growth of plant-based milk alternatives also could experience similar share as plant-based meat alternatives through 2030 (Figure 1A). The plant-based seafood alternatives market remains a small fraction of the overall plant-based alternatives market. However, the plant-based seafood market is anticipated to aggrandize over the next decade due to rapid downfall in global fish and shellfish stocks.

To meet the global consumer demand for plant-based meat, dairy, and seafood alternatives, global food producers and processors embracing plant-based alternatives. According to the Good Food Institute$_{SM}$ (GFI$_{SM}$ 2021b), a total of 668 alternative protein food manufacturing companies were producing plant-based alternative end-products in 2021 (Figure 1B). It is evident that the continuous shift in consumer dietary habits may encourage many food processing industries to develop consumer-centric plant-based alternatives. Moreover, the Good Food Institute$_{SM}$ raised funding opportunities (USD 3 billion) for alternative protein startups in 2020 compared to USD 1 billion in 2019, indicating that the research on alternative proteins received a great scientific attention and opportunities throughout the food industry value chain (GFI$_{SM}$ 2021c). Thus, global business to business

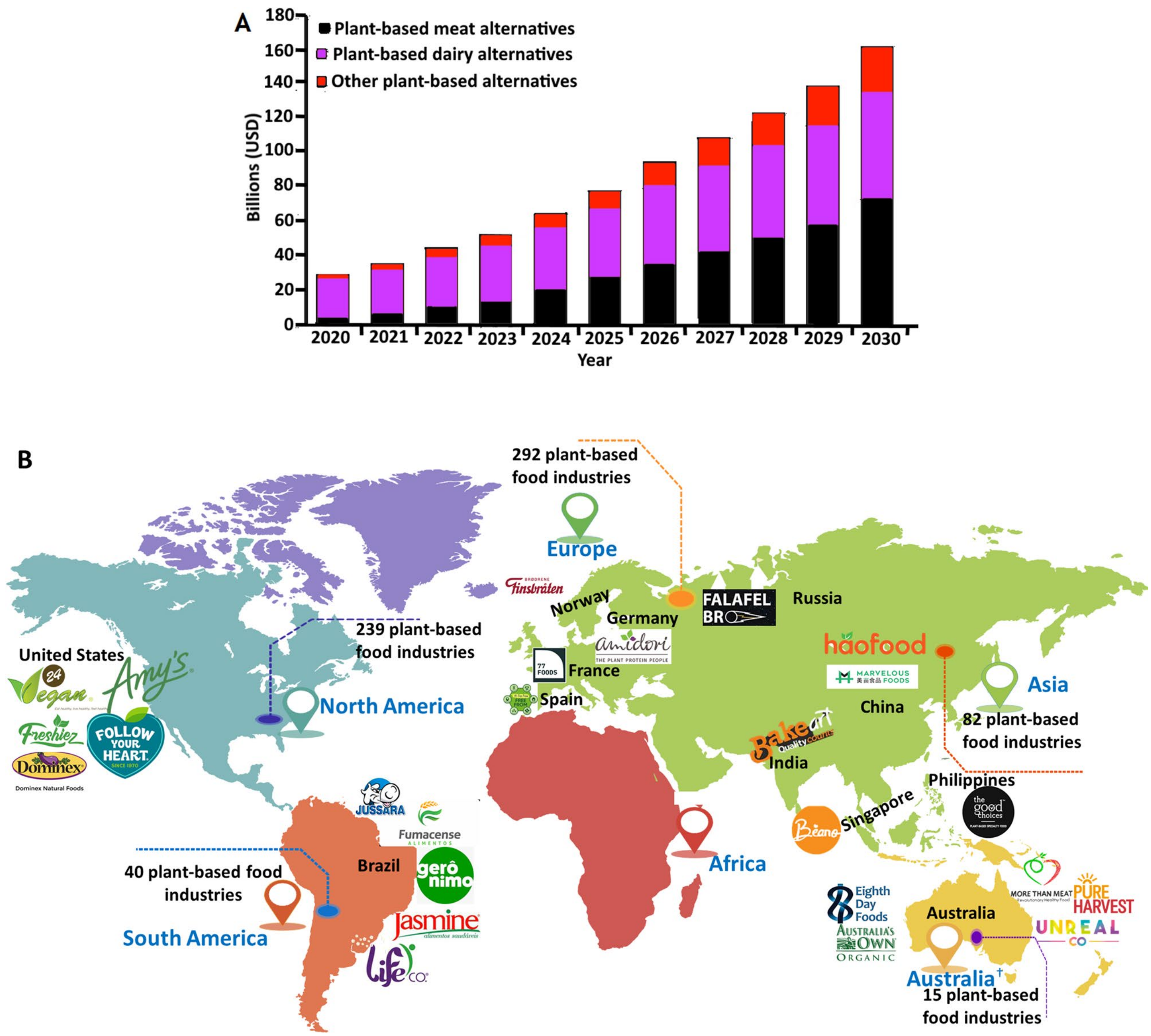


Figure 1. Plant-based alternatives in the health-conscious consumer market. Market value of plant-based meat, dairy, and other alternatives (A) and geographic distribution of plant-based alternative food industries (B). †indicates the addition of 3 plant-based alternative food industries from New Zealand. Sources: Bloomberg-Intelligence (2021) and the Good Food Institute$_{SM}$ (GFI$_{SM}$ 2021b).

companies emerged to embrace plant-based food supply chain; for instance, European countries are highly focused on plant-based alternatives with 292 plant-based food industries, followed by North America with 239, Asia with 82, South America with 40, and Australia (including New Zealand) with 15 plant-based food industries (Figure 1B). Interestingly, no food industry has yet emerged to develop plant-based alternatives in Africa. However, many European, North American, and Asian based food industries are key means of dominant food companies to enter and penetrate plant-based food supply in Africa. Among the 668-alternative protein-rich manufacturing food companies, 77 Foods (France), 24 Vegan® (United States), Bake art (India), life Co® (South America), and More than Meat (Australia) are few examples of alternative protein companies that prepare consumer-oriented plant-based meat, dairy, and seafood alternatives (Figure 1B). Obviously, both European and North American food companies had largely captured the market for plant-based alternatives, which could be related to consumer desire. Some of these industries are offering plant-based convenience meals, incorporating plant-based meat into prepared foods. Similarly, a US based startup company, Alpha Foods, offers >20 varieties of plant-based convenience meals incorporating plant-based chicken, sausage, and beef (Packaged-Facts 2020). In addition to plant-based alternatives, plant-based cellular agriculture also received an increased interest in the production of agriculture and food products, developing an alternative to the current production process for animal-based food products (Rischer, Szilvay, and Oksman-Caldentey 2020). However, the following section is limited to the nutritional profile of plant-based alternatives that have gained momentum and offer solutions to tackle health and environmental concerns. Thus, with improved taste, texture, and reduced price, many plant-based alternatives are expected to take over the market of health-conscious consumers moving plant-based alternatives from a niche to mainstream for a more sustainable and balanced diet over the next few years.

Nutritional profile of plant-based alternatives

The growing literature on plant-based foods has revealed that plant-based foods are proven to prevent many life-threatening diseases (Aune et al. 2017; López-Salas et al. 2021). Several advances in food processing and preparation methods improved the functionality and bioavailability of final plant-based food products. It is likely that the challenges of replacing animal-based foods with plant-based alternatives are achieved by new processing techniques that can mimic the product pliability as animal-based foods with improved nutrition, functionality, and great taste (Lonkila and Kaljonen 2021). Over the years, plant-based trends exclusively focused on creating new ways to deliver alternatives to animal-derived foods, such as plant-based meat, dairy, seafood alternative products (MovingMountains® 2020a, 2020b; Rincon, Braz Assunção Botelho, and de Alencar 2020). However, nutritional profile of plant-based alternatives is the key challenge while formulating plant-based alternatives, which should meet the nutrient content and quality attributes of the animal-based foods. Thus, the following section is focused on plant-based alternatives with more emphasis on nutritional composition delivering on the expectation of consumer health.

Plant-based meat alternatives

Generally, fresh meat, meat preparations, and processed meat products are the typical meat food classes, which was also adopted for the classification of plant-based meat alternatives, including meat analogs, meat preparation analogs, and processed meat analogs (Lusk et al. 2022; McClements et al. 2021). These are prepared from a variety of plant sources to resemble animal-based meats. A study by Curtain and Grafenauer (2019) compared the nutritional profile of 137 plant-based meat alternatives (50 burgers, 10 mince, 29 sausages, 24 chicken, 9 seafood, and 15 others) with meat products from four metropolitan Sydney supermarkets in Australia. All the plant-based meat alternatives were formulated with plant proteins, vegetable oils, cereals, vitamins, and minerals (Table 1). A comparative analysis reported that all plant-based meat alternatives with a high health star rating (i.e. rates the overall nutritional profile of similarly packaged foods in Australia and New Zealand) of 3.6–4.6, were low in energy, fat, and saturated fat, as well as high in carbohydrates, sugar, and dietary fiber. Sodium in plant-based mince was 6-fold higher than in animal-based meat mince but meat sausages showed 66% more sodium content than the plant-based sausages. Since all the plant-based products were fortified with iron, no difference was documented in the iron content of mince or sausages. The study also demonstrated the 5-times increased market growth for plant-based burgers. Similarly, another study by Harnack et al. (2021) conducted an in-depth survey in understanding nutritional composition of 37 branded plant-based ground beef alternative products available in the United States. The study reported a high nutritional strength for plant-based beef alternative products, such as saturated fat content of 4% daily value (DV), vitamin & minerals (10% DV), and dietary fiber (15% DV) as shown in Table 1. Most of the products reported less protein, zinc, and vitamin B_{12} than animal-based beef with a %DV of ≥10. Both studies recommended the plant-based meat alternatives as healthier and sustainable food supply. However, close comparison with animal-based products showed some nutritional strengths of plant-based alternatives but also some shortcomings that need to be filled for full acceptance of plant-based alternatives both from a sustainable and nutritional point of view.

With the aim of understanding nutritional and quality attributes of plant-based alternatives, Smetana et al. (2021) investigated nutritional and sensory analysis of plant-based beef burger patties using Nutri-Score scale system (−15 points (A) to +40 points (E) for nutrient content per 100 g) and nine-point-Likert-scale (1 = extremely bad and 9 = extremely good), respectively. For in-depth sensory analysis, a Just-About-Right-Scale (JAR) was used for bite firmness, color, flavor, meat taste, and salt taste. The nutritional analysis revealed the high Nutri-Score (B) for plant-based beef burger patties compared to animal-based burger patties (Nutri-Score of C to D). Both sensory analyses demonstrated the dislike slightly to like slightly (4 to 6) and an average JAR score of 27% for plant-based beef burger patties. These analyses further influenced the purchase intention (1 = would definitely buy and 5 = would definitely not buy) and willingness to pay (1 = 0.50 to–0.99 €, 3 = 1.50–1.99 €, and 6 = 3–3.49 €) the plant-based beef burger patties (3 to 4 points for both purchase intention and willingness to pay). Likewise, many evidence based systematic reviews highly focused on the development of plant-based meat alternatives, including the role of plant-based ingredients in additives (Kyriakopoulou, Keppler, and van der Goot 2021), production technologies, including low/high moisture extrusion technologies (Zhang et al. 2021), and sensory evaluation (Fiorentini, Kinchla, and Nolden 2020; Flores and Piornos 2021) of plant-based meat alternatives.

To increase the awareness of plant-based meat alternatives, Swing et al. (2021) compared the nutritional composition of four plant-based meat alternatives to traditional animal-based meats, such as ground pork (80% lean and 20% fat) and ground beef (80% lean and 20% fat). Legume proteins, oilseeds, cereals, purified fats & oils from coconuts, cocoa fruit, sunflower seeds, and rapeseed were used to mimic texture, quality, and elasticity of traditional animal-based meats. The nutritional analysis reported higher sodium (3230–4935 ppm) and calcium (214–1860 ppm) contents compared to both animal-based meats (sodium: 660 and 995 ppm; calcium: 106 and 180 ppm). In general, all the plant-based meat alternatives reported a high mineral content, potentially competing with the animal-based meats. Overall, this study indicated high similarity between the nutritional profile of both plant-based meat alternatives and animal-based meats except for mineral composition. Based on the similarity in nutritional profile, Crimarco et al. (2020)

Table 1. Nutritional profile of plant-based meat, dairy, and seafood alternatives[1].

Food product	Plant source	Nutritional facts (100 g)	Key findings	References
Plant-based meat alternatives				
Meat-free patties	Plant proteins, vegetable oils, starch, and added vitamins & minerals	Energy (176 cal), fat (7.20 g, in which saturated fat: 1.50 g), carbohydrates (16.70 g, in which sugars: 3.40 g), protein (9.60 g), fiber (5.30 g), sodium (372 mg), and iron (3.60 mg)	• Plant-based meat alternatives showed a similar appearance as animal-based meat with few nutritional shortcomings	Curtain and Grafenauer (2019)
Moving Mountains® sausage burger	Water, oyster mushroom, vegetable protein, vegetable oil, rice, wheat gluten, starch, natural flavoring, thickeners, oat fiber, vinegar, dextrose monohydrate, salt, lemon juice, preservatives, colorants, barley malt extract, and vitamin B_{12}	Energy (206 kcal), fat (14 g, in which saturated fat: 10 g), carbohydrates (6.50 g, in which sugars: 0.60 g), fiber (6.20 g), protein (11 g), and salt (1.60 g)	• No cholesterol, hormones, and antibiotics • Non-GMO ingredients	MovingMountains® (2020a)
Burger patties (pea and soy)	Plant proteins, vegetable oils, starch, and added vitamins & minerals	Energy (169 to 268 kcal), fat (10 to 19 g, in which saturated fat: 0.70 to 2.10 g), sugars (1.20 to 1.40 g), fiber (1.30 to 5.10 g), protein (14 to 18 g), and sodium (1.10 to 1.90 g)	• Plant-based burgers were more environmentally friendly than animal-based burgers	Smetana et al. (2021)
Beef (serving size: 3 oz)	Plant proteins, vegetable oils, starch, and added vitamins & minerals	Energy (155 kcal), fat (6.50 g, 4 % DV), carbohydrates (9.20 g), fiber (15 g, 15 % DV), protein (11.60 g), sodium (18 % DV), potassium (5 %), and iron (11 % DV)	• Plant-based beef showed nutritional strengths and shortcomings compared to animal-based ground beef	Harnack et al. (2021)
Grilled chicken strips (serving size: 3 oz)	Plant proteins, vegetable oils, starch, and added vitamins & minerals	Energy (130 kcal), fat (3.50 g, in which saturated fat: 0 g), carbohydrates (6 g), fiber (3 g), protein (22 g), and sodium (340 mg)	• Intake of plant-based chicken stripes may reduce the risk of cardiovascular risk factors • Reduced serum trimethylamine-N-oxide and LDL-cholesterol levels in the human body	Crimarco et al. (2020)
Beef (serving size: 113 g)	Plant proteins, vegetable oils, starch, and added vitamins & minerals	Energy (250 kcal), fat (14 g, in which saturated fat: 8 g), carbohydrates (9 g, in which sugars: 0 g), fiber (3 g), protein (19 g), potassium (610 mg), and calcium (180 mg)	• Nutritional profile of both plant-based beef and grass-fed ground beef showed distinct differences	van Vliet et al. (2021)
Dopsu™ no lamb pieces	Water, vegetable proteins, rapeseed oil, wheat powder, pea protein, potato starch, thickener, gelling agent, mint, seasoning, salt, and barley malt extract	Energy (215 kcal), fat (9.40 g, in which saturated fat: 0.70 g), carbohydrates (7.90 g, in which sugars: 0.50 g), fiber (5.10 g), protein (22 g), and salt (0.86 g)	• High protein, low salt, and low saturated fat • Soy and palm-oil free	DOPSU™ (2020)
OmniPork	Water, protein blend, thickeners, yeast extract, potato starch, cane sugar, salt, natural flavor, barley malt extract, colorants, dextrose, and shiitake mushroom	Energy (82 kcal), fat (1.60 g, in which saturated fat: 0.30 g), carbohydrates (6.80 g, in which sugars: 0.90 g), fiber (4.60 g), protein (12.50 g), and cholesterol (0 g)	• No hormones and antibiotics • Non-GMO ingredients	OmniFoods® (2018)
Plant-based dairy alternatives				
Chick pea and coconut milk blend	Chick pea, water, and coconut	Fat (0.39 to 7.42 g), carbohydrates (0.67 to 3.49 g), ash (0.32 to 0.43 g), protein (1.04 to 2.10 g), sodium (1.19 to 8.55 mg), calcium (107.41 to 131.26 mg), and potassium (156.56 to231.60 mg)	• Chickpea extracts with 10 and 30 % of coconut received a high consumer acceptability • Addition of vanilla flavor increased the consumer acceptability (6.40 = like slightly to like moderately) • Comparable nutritional composition as traditional cow milk	Rincon, Braz Assunção Botelho, and de Alencar (2020)

(Continued)

Table 1. (Continued)

Food product	Plant source	Nutritional facts (100 g)	Key findings	References
Soy-almond milk blend (60 % almond milk)	Soy, water, and almond	Fat (7.10 g), total solids (21.71 g), ash (2.36 g), protein (2.43 g), calcium (12.72 mg), titratable acidity (0.32 g), and iron (0.37 mg)	• No lactose and allergens • Received comparable nutritional and sensory profile as traditional cow milk	Kundu, Dhankhar, and Sharma (2018)
Grains-based milk (serving size: 100 mL)	Water, oat, rice, and quinoa	Energy (48.32 kcal), fat (1.35 g, in which saturated fat: 0.20 g), carbohydrates (8.21 g, in which sugars: 4.74 g), protein (0.56 g), fiber (0.56 g), salt (0.13 g), calcium (120 mg), and potassium (151 mg)	• Fortification improved the nutritional profile of grains-based milk	Clegg et al. (2021)
Mixed plant-based milks	Water, coconut/almond, almond/oat, coconut/rice, and rice/almond	Energy (45 kcal), fat (1.39 g, in which saturated fat: 0.68 g), carbohydrates (7.72 g, in which sugars: 5 g), protein (0.29 g), fiber (0.09 g), salt (0.10 g), calcium (120 mg), and vitamin B_{12} (0.38 µg)	• Differences in nutritional composition were observed between plant and animal-based milks	Clegg et al. (2021)
Quinoa fermented beverage	Quinoa seeds, raspberry sirup, probiotic culture, and water	Fat (0.57 g), protein (0.57 g), fiber (0.43 g), ash (0.04 g), and total solids (5.63 g)	• Fermentation improved the acceptability of quinoa beverage • Addition of raspberry sirup improved the consumer acceptability • High probiotic potential (> 6 CFU/mL lactic acid bacteria cocci)	Karovičová et al. (2020)
Legume beverages (serving size: 100 mL)	Pea, chickpea, water, and lupin	Carbohydrates (3.26 to 9.01 g), glucose (0.06 to 0.45 g), and protein (1 to 2.50 g)	• High milk yield • Chickpea beverage with cooking water received the best taste • Non-Newtonian behavior	Lopes et al. (2020)
Soft cheese	Soya milk, water, and coagulants (lime, alum, and steep water)	Fat (33.85 to 38.85 g), carbohydrates (8.09 to 13.01 g), ash (2.63 to 3.21 g), protein (40 to 41.40 g), and fiber (2.48 to 3.12 g)	• Improved water absorption capacity, oil absorption capacity, foam capacity, and gelation capacity • Cheese prepared with lime received a high sensory acceptability	James et al. (2016)
Soy, coconut, cashew, almond, and hemp-based yogurts	Soy, coconut, cashew, almond, water, hemp, thickener, flavorings, nondairy yogurt culture, vitamins, salt, colorants, and acidity regulators	Energy (38 to 50 kcal), fat (2 to 7.90 g, in which saturated fat: 0.20 to 4.20 g), carbohydrates (1 to 8 g, in which sugars: 0.60 to 4.30 g), protein (0.60 to 4.60 g), fiber (0.10 to 1 g), and salt (0.03 to 0.40 g)	• The soy, coconut, and cashew-based yogurts possessed a comparable texture to the animal-based dairy yogurt • Presence of hydrocolloids, sweeteners, and flavors improved the sensory acceptability of yogurt and comparable to animal-based dairy yogurt	Grasso et al. (2021)
Plant-based kefir	Hazelnut milk, kefir culture, and water	Fat (1.55 to 4.02 g), carbohydrates (3.23 to 3.99 g), protein (0.65 to 4.17 g), fiber (0.40 g), ash (0.20 g), and total solids (5.30 to 9.60 g)	• Hazelnut milk enhanced the growth of yeasts in kefir • Hazelnut milk improved the viscosity, consistency index, water holding capacity, and exopolysaccharide content of kefir • Improved the total phenolics and antioxidant capacity of kefir	Atalar (2019)
Plant-based seafood alternatives				
Moving Mountains® fish fingers	Water, wheat flour, soya protein concentrate, vegetable oil, starch, thickener, natural flavorings, salt, maltodextrin, spice extract, and spices	Energy (233 kcal), fat (11.90 g, in which saturated fat: 1.30 g), carbohydrates (19.60 g, in which sugars: 0.50 g), fiber (3.90 g), protein (10 g), and salt (0.90 g)	• Flaky texture and wrapped in crunchy golden breadcrumbs • No mercury, cholesterol, hormones, and antibiotics • Non-GMO ingredients	MovingMountains® (2020b)

(*Continued*)

Table 1. (Continued)

Food product	Plant source	Nutritional facts (100 g)	Key findings	References
Moving Mountains® fish fillets	Water, wheat flour, soya protein concentrate (12.85 %), vegetable oil, starch, thickener, natural flavorings, modified maize starch, salt, maltodextrin, dextrose, and spices	Energy (230 kcal), fat (12.40 g, in which saturated fat: 1.40 g), carbohydrates (16.90 g, in which sugars: 0.80 g), fiber (4.50 g), protein (10 g), and salt (0.90 g)	• Flaky texture and wrapped in panko golden breadcrumbs • No mercury, cholesterol, hormones, and antibiotics • Non-GMO ingredients	MovingMountains® (2021)
Fish steaks	Water, breadcrumb coating, konjac flour, tapioca starch, wheat starch, salt, natural flavorings, sugar, wheat fiber, yeast extract, carrageenan, potassium sorbate, and titanium dioxide	Energy (136 kcal), fat (5.70 g, in which saturated fat: 0.40 g), carbohydrates (17.80 g, in which sugars: 1.10 g), fiber (2.70 g), protein (2 g), and salt (1.20 g)	• 100 % vegan food • Low calories, high fiber, more sustainable than traditional fish	V™Bites (2020)
Salmon slices	Water, rapeseed oil, soya protein, carrageenan, konjac flour, potato starch, sea salt, onion powder, sugar, natural flavorings, potassium sorbate, smoke flavoring, annatto, and iron oxide	Energy (125 kcal), fat (9.20 g, in which saturated fat: 0.60 g), carbohydrates (4.50 g, in which sugars: 0.50 g), fiber (1 g), protein (5.70 g), and salt (1.20 g)	• Reduced salt, 100 % vegan, and less calories	V™Bites (2020)
Fishless fingers	Rice flake, wheat flour, mycoprotein (12 %), water, natural flavoring, rapeseed oil, methylcellulose, yeast, salt, paprika, and paprika extract	Energy (214 kcal), fat (7.80 g, in which saturated fat: 0.60 g), carbohydrates (29 g, in which sugars: 1.60 g), fiber (4.20 g), protein (4.50 g), and salt (1.30 g)	• Low saturated fat, high fiber, and no soy	Quorn™ (2020)
Breaded crab cake (per serving)	Water, Good Catch® 6-plant protein blend, sunflower oil, wheat flour, red bell peppers, corn starch, green onions, parsley, natural flavors, salt, lemon juice, methylcellulose, corn maltodextrin, organic cane sugar, onion powder, spices, paprika, yeast extracts, garlic powder, yeast, corn flour, xanthan gum, annatto, and acetic acid	Energy (220 cal), fat (11 g, in which saturated fat: 1 g), carbohydrates (15 g, in which sugars: 1 g), protein (15 g), sodium (520 mg), and potassium (150 mg)	• High protein • Crab meat style texture	Good®Catch (2021)
Ahimi®- plant-based alternative to raw tuna (serving size: 3 oz)	Tomato, soy sauce, sugar, water, and sesame oil	Energy (15 cal), fat (0 g), carbohydrates (3 g), protein (1 g), sodium (480 mg), and potassium (68 mg)	• Gluten free and non-GMO ingredients • No cholesterol	Ocean-Hunger-Foods® (2021)
Unami™- plant-based alternative to freshwater eel	Eggplant, gluten-free soy sauce, mirin, sugar, rice bran oil, algae oil, and konjac powder	Energy (30 cal), fat (0 g), carbohydrates (7 g), protein (1 g), sodium (540 mg), and potassium (70 mg)	• Gluten free and non-GMO ingredients	Ocean-Hunger-Foods® (2021)
Tuna paté	Water, wheat gluten, vegetable oil, soya protein, non-hydrogenated vegetable fat, wheat fiber, yeast extract, natural flavoring, salt, onion powder, sugar, dried yeast, thickeners, black pepper, malt extract, garlic powder, and iron oxide	Energy (243 kcal), fat (17.40 g, in which saturated fat: 5 g), carbohydrates (5 g, in which sugars: 1.20 g), fiber (3.60 g), protein (16.30 g), and salt (1.80 g)	• Protein rich and non-GMO ingredients	V™Bites (2020)
Plant-based new wave shrimp® (serving size: 75 g)	Water, mung bean protein, potassium alginate, sunflower oil, modified potato starch, calcium lactate, hydrogenated vegetable oil, natural & artificial flavor, sea salt, sugar, fructose, konjac powder, potassium citrate, and sunflower lecithin	Energy (80 cal), fat (3.50 g, in which saturated fat: 1.50 g), carbohydrates (7 g, in which sugars: 1 g), protein (5 g), sodium (320 mg), calcium (180 mg), and potassium (620 mg)	• No shellfish allergens • No soy and gluten-free	New-Wave-Foods® (2021)

[1]oz = ounce, GMO = genetically modified organism, % DV = % daily value, LDL = low-density lipoprotein, and CFU = colony-forming unit.

compared the effect of 7 plant-based meat alternatives with 6 animal-based foods on serum and cardiovascular disease risk factors in 36 healthy omnivorous adults of ≥18 years. Participants receiving plant-based meats showed significantly ($p < 0.05$) lower serum trimethylamine-N-oxide (3 µM), LDL-cholesterol (110 mg/dL), and body weight (79 kg) against to serum trimethylamine-N-oxide (5 µM), LDL-cholesterol (121 mg/dL), and body weight (80 kg) in-group receiving animal-based meats. This demonstrated that the consumption of plant-based meat alternatives reduced the risk associated with cardiovascular disease and obesity.

In contrast to these findings, another recent study by van Vliet et al. (2021) concluded the differences in nutritional composition of plant-based meat alternative ($n = 18$) and grass-fed ground beef ($n = 18$) based on metabolomics analysis. Metabolomics revealed 90% differences in metabolite profiles between grass-fed ground beef and the plant-based meat alternative. Plant-based meat alternatives exclusively reported a high quantity of 67 metabolites, such as phytosterols, antioxidants, and vitamins, which were absent in grass-fed ground beef. On the other hand, grass-fed ground beef documented a greater quantity of 51 metabolites, including docosahexaenoic acid (ω-3), niacinamide, glucosamine, hydroxyproline, and antioxidants (e.g. anserine, spermine, and squalene). Based on the metabolomics analysis, nutritional profile of both plant-based meat alternative and grass-fed ground beef showed distinct differences, indicating that these products may be considered as complementary in terms of nutrients but should not be viewed as nutritionally interchangeable. However, choosing the right protein source is essential to develop plant-based alternatives of meat products, which further can be fortified with essential nutrients to recreate its functionality and texture as animal-based meats.

Plant-based dairy alternatives

The plant-based dairy alternatives have been consumed for centuries; however, its popularity has skyrocketed over the past decade due to its numerous positive health effects on the human body. Now, a variety of plant-based ingredients, emulsifiers, and flavorings are used in preparation of healthy and nutritious plant-based dairy alternatives to boost texture, taste, sweetness, mouthfeel, and nutritional value. Rincon, Braz Assunção Botelho, and de Alencar (2020) developed a plant-based milk using coconut and chickpea extracts ranging from 50% to 100%. The protein and calcium contents ranged from 1 to 2 g/100 g and 107 mg/100 g to 131 mg/100 g, respectively (Table 1), compared to 3.2–3.4 g/100 g proteins and around 1.2 g/100 g calcium contents in traditional milk. The Brazilian panelists rated the good score (>5 = neither like or dislike to like slightly) for overall acceptability of plant-based milk, which was further increased to 6.40 (like slightly to like moderately) after addition of vanilla flavor. By maceration of soy and almonds, Kundu, Dhankhar, and Sharma (2018) prepared the plant-based milk using soy and almond milks. The optimized formulations of 1:1 water to sample (soy or almond) were used for the development of 100% soymilk, 100% almond milk, and their blend (soy-almond milk blend containing 60 –100% almond milk). In comparison, soymilk exhibited high moisture (92%), pH (7) and protein content (3%), whilst almond milk reported high total solids (28%), titratable acidity (0.4%), ash (3%), fat (8%), iron (4 mg/100 mL), and calcium (16 mg/100 mL). The soy-almond milk blend (60% almond milk) reported higher nutritional and proximate composition than soy and almond milks, while lower calcium and protein contents than control (cow milk). The 10 semi-trained panelists recommended the soy-almond milk blend (60% almond milk) with higher acceptability (8.20) than soymilk (6.56) but lower than control (cow milk; 8.73) and almond (8.46) milks. To improve the plant-based milk flavor and nutritional value, several reviews highlighted the application of fermentation technologies (mixed-culture fermentation) (McClements, Newman, and McClements 2019; Tangyu et al. 2019), which led to the development of plant-based cheese and yogurt to meet the demand on dairy alternatives.

James et al. (2016) developed soft cheese from soya milk using lime, alum, and corn steep water (i.e. the solution resulting from corn steeping in water) as coagulants. The use of coagulants influenced the chemical and functional properties of the soft cheese with high acceptability for cheese produced by lime. Likewise, Mattice and Marangoni (2020) formulated a zein cheese containing 0%, 10%, 20%, and 30% zein (starch to fat ratio of 2:1) and compared with commercially available cheddar cheese. The cheese developed with 30% zein resembled commercial cheddar cheese in terms of softness, texture, stretchability, and viscosity, indicating the potential as affordable and more sustainable cheese to replace animal-based cheese. With the similar concept, Grasso et al. (2021) compared the composition, structure, and physicochemical properties of four commercially available plant-based block-style products (i.e. vegan cheese) with those for cheddar and processed cheeses. The plant-based block-style products significantly showed a lower protein content (0.1–3%) with discrete network and lower meltability (5–21%) than the protein content (25% and 18%) and meltability (1.7–49%) of cheddar (25%) and processed cheeses (18%). Other textural and rheological properties also showed significant differences to those of cheddar and processed cheeses; moreover, the variations in thermal properties were observed at ~10 °C and ~30 °C for cheddar and processed cheeses, while at 20 °C for plant-based cheese. This demonstrated that the composition, structure, and physicochemical properties of the plant-based cheese might have been influenced by their formulations and thus ingredients used in preparation of plant-based cheese may play a vital role to design an alternative plant-based cheese to traditional dairy-based cheese.

In addition to the plant-based cheese, many studies used food fermentation technologies that ferment the plant-based extracts to obtain similar consistency as traditional milk, which further improved the sensory, nutritional, and textural properties of plant-based dairy products. Moreover, fermentation helps to lower the antinutritional components of plant-based ingredients. Two independent studies compared the composition, physicochemical, and sensorial properties (Grasso, Alonso-Miravalles, and O'Mahony 2020) as well as dynamic texture (Greis et al. 2020) of commercial plant-based yogurts and dairy yogurt. The former study showed the high similarity in textural, rheological, and sensory parameters of plant-based yogurts and dairy yogurt. The latter study solely focused on dynamic textural perception of five plant-based yogurts and two dairy yogurts using temporal dominance of sensations (i.e. a sensory method that studies the dominant sensation of a product over time) with 87 consumers. The plant-based yogurts showed a higher variation in the mouthfeel sensation compared to a stable mouthfeel sensation for dairy yogurts. Nevertheless, the degree of likeness and attributes of their mouthfeel were similar for both products. Thickness and creaminess were the two major temporal drivers of plant-based yogurts that increased the consumer likeliness during mastication. Both the studies collectively identified the role of key quality attributes and their relationship of plant-based yogurts, which should be taken into consideration during the product development process to mimic the similar quality attributes as traditional animal-based yogurts.

By using coconut milk without or with addition of 0.5–2%, w/w of tapioca starch, Pachekrepapol, Kokhuenkhan, and Ongsawat (2021) formulated yogurt-like product and evaluated physicochemical, rheological, and sensory attributes at 4 °C over a 14-day storage. The increase of tapioca starch content showed an increase in storage modulus G' (80–700 Pa), a decrease in syneresis (22–8%), but no significant change in whiteness index (78–79, $p > 0.05$). The yogurt formulated with 1% tapioca starch contained 20% fat, 6% carbohydrates, and 6% protein, which was further received a high sensory acceptability (~7 = like moderately for color, aroma, flavor, and overall acceptability). Similarly, physicochemical properties and sensory parameters of the legume (soy, pea, and mung bean) based yogurts were independently investigated by Yang et al. (2021) and Rahmatuzzaman Rana, Babor, and Sabuz (2021). Both studies reported the good physicochemical properties with high overall acceptability (~7 = like moderately) of legume-based yogurts, indicating the potential of consumer-accepted legume-based yogurt alternatives to traditional yogurts. High-pressure processing was applied to improve the characteristics of yogurts made from legume or potato protein isolate (Levy et al. 2021; Sim, Hua, and Henry 2020). The application of high-pressure technology reduced the particle size, improved the stability, as well as viscoelastic properties of legume-based and potato protein-isolate based yogurts. In addition, all the quality attributes and appearance of the high-pressure treated samples resembled to commercial dairy yogurts, demonstrating the feasibility of using high-pressure processing to develop plant-based yogurts. Over the years, many plant-based dairy alternatives (kefir-like fermented and fermented legume-based beverages) gained attention in every form of dairy alternative due to massive importance of nondairy probiotic products and their positive impact on health (Bonke, Sieuwerts, and Petersen 2020; Lopes et al. 2020; Łopusiewicz et al. 2019; Verni et al. 2020).

Plant-based seafood alternatives

The plant-based seafood alternatives are the emerging category of the overall plant-based alternatives. Moreover, the present trend represents a clear market opportunity for plant-based seafood alternatives. Generally, a wide variety of plant ingredients, such as plant protein isolates, soy, starch, vegetable extracts, edible oils, additives, and colorants are used to mimic the similar texture and taste as traditional seafood products.

To improve the environmental sustainability and reduce over-fishing, Moving® Mountains launched plant-based frozen fish fingers (MovingMountains® 2020b). The product contains mixture of plant ingredients, including legume proteins, starch, vegetable oils, flavorings, spices, and thickeners, which offers plant-based protein (10 g/100 g), carbohydrates (19 g/100 g), energy (233 kcal/100 g), zero cholesterol & mercury, and 100% free of hormones & antibiotics. In the following year, Moving®Mountains also launched a plant-based frozen fish fillets (MovingMountains®, 2021) using similar plant-based ingredients as plant-based frozen fish fingers along with modified starch and dextrose (Table 1). Both the products have a succulent flaky texture and are coated in breadcrumbs. Likewise, V™Bites launched five plant-based fish products, such as fish steaks, salmon slices, fish cake, fish fingers, and tuna paté (V™Bites, 2020). These plant-based fish products were made from a variety of plant ingredients, vegetable oils, preservatives, flavoring agents, and thickeners that offers a basic nutritional composition, including protein (2–16 g/100 g), carbohydrates (4.5–18 g/100 g), zero cholesterol & mercury, and energy (125–243 kcal). The addition of a variety of plant ingredients provided the indistinguishable texture and flavor as traditional fish products, indicating the resemblance of plant-based fish products to traditional fish products with more sustainability in food systems by relieving pressure on the depleting ocean fisheries.

On the other hand, spurred consumer demand led to the development of different sustainable seafood options. For instance, many global plant-based seafood entrants rolled out plant-based seafood alternatives (shrimp, Unami™ raw eel, cavi.art®, fish burgers, crab cakes, smoked salmon, and tuna chunks) on the market (Kazir and Livney 2021). However, these food industries may not target to imitate the structure and texture of traditional seafood, which should be investigated through novel manufacturing technologies and understanding of chemical & nutritional composition to obtain better structural and sensorial properties to the final product, thereby reaching the consumer expectation in mimicking the taste, smell, appearance, and texture of the real seafood products.

Gastrointestinal digestion and bioavailability

Proteins are a major source of energy and essential amino acids in the human diet, which mostly comes from plant or animal-based foods. It is well-known that the digestion process of plant-based foods is different from animal-based foods in terms of their nutrients digestion and absorption rates within the gastrointestinal tract (McClements and Grossmann 2021), which could be related to their compositions, processing conditions, and structures. This may possess a doubt on digestibility of a wide variety of plant-based foods, including plant-based alternatives. Over the years, plant-based meat, dairy, and seafood alternatives received a popularity to replace animal-based foods due to their health benefits as well as comparable nutritional composition and appearance (Zhou, Hu, et al. 2021). However, these plant-based alternatives are formulated with a wide variety of plant-based ingredients (Kyriakopoulou, Keppler, and van der Goot 2021). Thus, different ingredients and processing conditions used to design plant-based alternatives may affect digestion and absorption of nutrients in the human body. Martínez-Padilla et al. (2020) evaluated the *in vitro* protein digestibility of four commercial plant-based milk alternatives (plant-based almond, hemp, oat, and soymilk with a protein content higher than 1 g/100 mL) in comparison with traditional whole cow milk (3.5% fat) and bovine serum albumin (positive control). The gastrointestinal protein digestion was simulated using a multi-step static *in vitro* protein digestibility model system containing pepsin and pancreatin. This study concluded the significant variability *in vitro* protein digestibility of plant-based milk alternatives (oat and almond drinks) and bovine serum albumin. Wang et al. (2021) used an advanced dynamic digestion model (i.e., human gastric simulator) to study the microstructural changes, physicochemical stability, and protein digestibility of soymilk. The presence of pepsin influenced the gastric emptying of proteins and lipids within 45 min and 15 min, respectively during gastric digestion (Figure 2A). This revealed the faster gastric emptying with the addition of pepsin during gastric digestion, indicating the fate of soymilk in the digestive tract.

To improve the nutritional composition and absorption of nutrients during and after digestion, several studies employed the fortification of plant-based milks vitamins and minerals. Silva et al. (2020) evaluated the mineral bio-accessibility of 25 plant-based milks along with sterilized cow milk. The *in vitro* bio-accessibility was performed by dialysis after gastric and intestinal digestions. Plant-based milks fortified with calcium compounds showed a higher calcium bio-accessibility than cow milk. The plant-based milks exhibited high amounts of total magnesium and dialyzed magnesium, while low amounts of dialyzed iron and zinc. According to the Recommended Daily Intake (RDI), plant-based milk samples were able to provide higher %RDI than cow milk, indicating the possibility of plant-based milks delivering the similar or higher amount of RDI than traditional cow milk. Likewise, Zhou, Zheng, et al. (2021) evaluated gastrointestinal digestion of vitamin D nanoemulsion fortified plant-based milks by harmonized INFOGEST *in vitro* gastrointestinal tract. The vitamin D nanoemulsion fortified plant-based milks showed no effect on lipid digestion (120–140%) with low vitamin D bio-accessibility (20–23%). By using the immobilized vitamin B_2 with 4% okra (*Abelmoschus esculentus;* ladies' finger) for soymilk fermentation, Feng et al. (2021) studied the *in vitro* digestion of

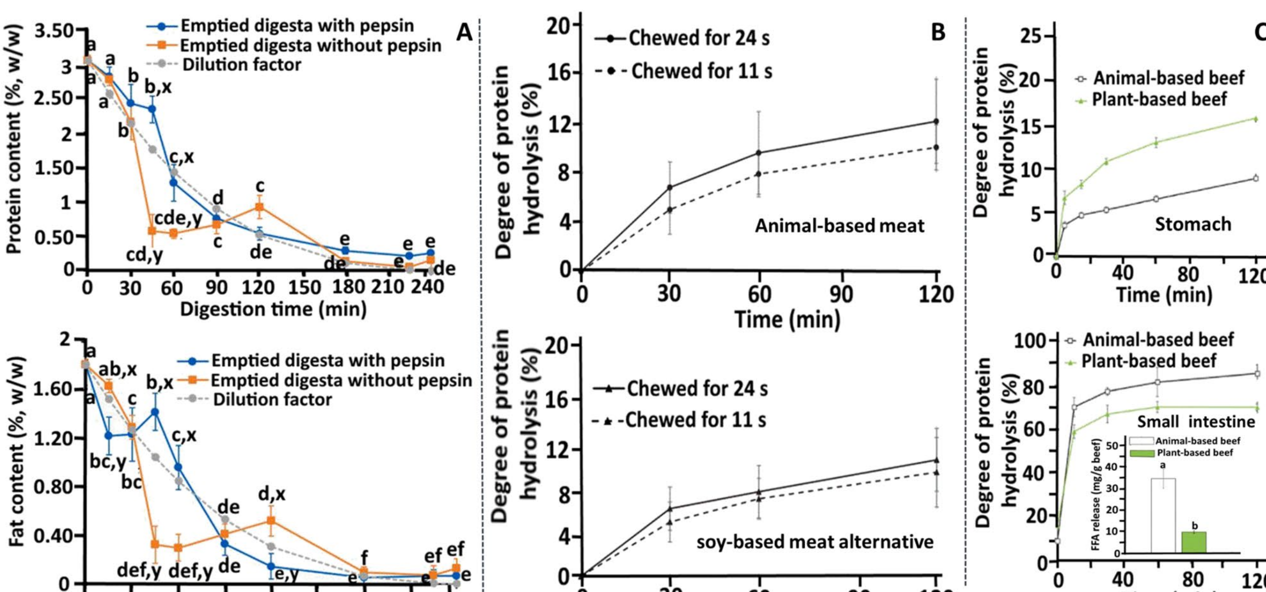


Figure 2. *In vitro*-gastrointestinal digestion of plant-based alternatives. Total protein and fat contents of the emptied digesta of soy milk during gastric digestion (A), *in vitro* gastric degree of protein hydrolysis of soy-based meat alternative and animal-based meat (B), and protein hydrolysis of plant-based beef and animal-based beef during simulated stomach and small intestinal conditions along with an inset showing their release of free fatty acids for plant-based beef and animal-based beef during simulated small intestinal conditions (C). The results were expressed as mean ± standard deviation of ≥ 3 independent replicates and error bars represent the standard deviation from the mean values. In Figure 2A, mean values with different lower-case alphabets (a to f) and (x and y) represents significant difference ($p < 0.01$; *post-hoc* Tukey's honest significant difference test) within a treatment (with/without addition of pepsin) and digestion time, respectively, while in Figure 2C, lower-case alphabets (a and b) represent significant difference ($p < 0.05$; *post-hoc* Tukey's honest significant difference test) between the samples. FFA = free fatty acids. Adapted with permission from Wang et al. (2021), Chen, Capuano, and Stieger (2021), and Zhou, Hu, et al. (2021).

fermented soymilk. After bio-enrichment of okra and vitamin B_2, fermented soymilk exhibited high soy protein digestibility, demonstrating the improved soy protein digestibility and bio-accessibility in the human body. With the similar concept, two independent studies improved the *in vitro* gastrointestinal digestion of plant-based milks (Dugardin et al. 2020; Zheng, Zhou, and McClements 2021; Zhou, Liu, et al. 2021).

On the other hand, Baugreet et al. (2019) investigated the bio-accessibility of protein-enriched plant-based restructured beef steaks using the static INFOGEST method. Protein hydrolysis was observed during gastrointestinal digestion with the production of lower molecular weight peptides <500 Da compared to animal-based restructured meat. Similarly, Chen, Capuano, and Stieger (2021) compared the *in vitro* gastric and intestinal protein digestion of soy-based meat alternative and animal-based meat based on oral processing behavior with a natural chewing time of 11 and 24 s by healthy adults (aged 25 years). The chewing time of 24 s showed the higher *in vitro* gastric degree of protein hydrolysis (soy-based meat alternative: 9% and animal-based meat: 12%) compared to chewing time of 11 s (soy-based meat: 8% and animal-based meat: 10%) as shown in Figure 2B. The *in vitro* intestinal degree of protein hydrolysis for the chewing time of 24 s also followed the similar trend as *in vitro* gastric with high *in vitro* intestinal degree of protein hydrolysis (soy-based meat alternative: 69% and animal-based meat: 89%). This result indicated the higher *in vitro* gastric and intestinal degree of protein hydrolysis for animal-based meat compared to soy-based meat alternative irrespective of chewing time. To understand the protein and lipid digestion patterns in simulated human gut, Zhou, Hu, et al. (2021) compared the digestibility and gastrointestinal fate of plant-based beef and animal-based beef (extra lean) using standardized INFOGEST *in vitro* digestion model. The animal-based beef exhibited 9% and 76% of protein digestion in the stomach and small intestinal conditions, respectively, which was lower than that of the plant-based beef (16%) in the stomach, while higher than the plant-based beef (54%) in the small intestine (Figure 2C). Moreover, the lipid digestion (i.e. free fatty acids release) of the plant-based beef (8 mg/g beef) was lower than the animal-based beef (33 mg/g beef) (Figure 2C). The differences in protein type (globular soy and fibrous beef proteins), structure, and dietary fiber led to the variances in the lipid and protein digestion of both plant-based beef and animal-based ground beef. A study by Lin et al. (2022) investigated the protein digestibility of textured-wheat-protein-based meat analogue using extrusion. The plant-based meat analogue showed the high protein digestion in gastric and small intestinal digesta with high degree of proteolysis, suggesting the effect of extrusion moisture that promoted the diffusion of proteases to the cleavage sites.

Since the seafood alternatives is an emerging segment with few fish and shrimp products (Kazir and Livney 2021; MovingMountains® 2020b), no single study thoroughly discussed the gastrointestinal fate of plant-based seafood alternatives. However, structural and compositional complexity in plant-based alternatives may limit the gastrointestinal digestion and the absorption of essential nutrients compared to animal-based foods. Although *in vitro* digestion models have boosted the area of digestion studies for plant-based alternatives, it is difficult to mimic the complexity of the digestive tract outside the body. Moreover, *in vitro* digestion models are preliminary screening methods that may provide no correlation data applicable to clinical or *in vivo* studies. Thus, realistic *in vitro* models or *in vivo* studies or combined strategies should be developed to screen the bioavailability and digestibility of plant-based alternatives.

Regulatory frameworks and labeling claims of plant-based alternatives

Due to growing interest in plant-based alternatives, many food-processing industries are seeking opportunities to establish their brand or wide variety of plant-based alternatives in the consumer market. In the context of the increasing development of plant-based alternatives, regulatory frameworks and labeling claims should be a principal consideration for food industries during manufacturing, supplying, and marketing. To protect consumers, both from unsafe substances and from misleading practices of food industries, certain standards are needed to deal with plant-based alternatives. However, these standards are still at a preliminary stage due to the controversy in labeling of plant-based alternatives with reference to the animal-based counterparts. For example, the Court of Justice of the European Union (CJ-EU, 2017), clarified that the purely plant-based products cannot be legally labeled or marketed using dairy terms, such as milk, yogurt, and cream. However, this was not applicable to plant-based meat and seafood alternatives. Thus, plant-based dairy alternatives cannot be referred to with dairy-associated terms or phonetically similar terms. In Australia, it is legally allowed to use the term milk for plant-based dairy alternatives, for instance, soymilk (Leialohilani and de Boer 2020). According to Canadian Food and Drug Regulations, plant-based dairy alternatives are referred to as beverages instead of milk, which was much controversy in the United states, where the term milk in the labeling of plant-based alternatives, is acceptable (Musa-Veloso and Juana 2020). However, the Dairy Pride Act of the United States prohibited the use of terminology like milk, yogurt, and cheese in the labeling of plant-based alternatives (Dairy-Pride-Act 2021). Also, the Real Marketing Edible Artificials Truthfully (MEAT) Act of 2019 was put forward in the United States Senate to use the term, imitation, for all plant-based meat alternatives (Real-MEAT-Act 2019).

In Asia, China is currently amending food labeling standards and regulations on plant-based alternatives. All ingredients must be plant-based and are lawful to use in food under Chinese food laws. The proper labeling should be used to promote the plant-based alternatives, including appropriate product name, qualifiers, and claims (National-Law-Review 2020). Moreover, the Chinese Institute of Food Science and Technology (CIFST 2020) issued drafted regulations on plant-based foods as well as plant-based meat alternatives and invited Chinese food industries, stakeholders, and consumer associations to solicit feedback on drafted regulations for plant-based alternatives. Unlike China, there are no well-defined regulations on plant-based alternatives in India, but the food products should comply with labeling requirements. According to the new Food Safety and Standards Amendment Regulation draft issued by Food Safety and Standards Authority of India (FSSAI 2020), the use of dairy terminology like milk, butter, yogurt, and cheese on plant-based dairy alternatives was legally prohibited.

On the other hand, the Plant Based Foods Association (PBFA) prepared voluntary standards to promote consistency in labeling of plant-based meat alternatives in the United States (PBFA 2019). The PBFA, in collaboration with NSF® International launched a certified plant-based seal to differentiate from the vegan label (Figure 3A), which is prominently displayed on the front of the package of 77 manufacturing companies (722 plant-based products), including Albertsons® Companies and Tofurky plant-based alternatives (Figure 3B and 3C). However, in the long-term, national and international agencies should draft appropriate standards to label properly the plant-based alternatives to avoid misleading the consumer while purchasing the products. These regulatory frameworks should also provide legal clarity for food business operators to invest in plant-based food research and development. To promote international trade, national agencies should introduce specific guidelines for plant-based alternatives to help consumers in decision-making and shift their choice of selection from animal-based to more healthy and sustainable plant-based alternatives.

Consumer perception and acceptance of plant-based alternatives

Over the years, the consumer perception on food products has significantly changed due to disposable income, globalization, education, health awareness, and uplift in lifestyle as well as family structure. The majority of modern consumers are demanding to lean into products that are high sustainable and eco-friendly. In addition, the ingredients used in food manufacturing, processing methods, and addition of ingredients to the food plays an important role in food choice and consumer interest. Therefore, many food-processing industries are following the 'clean label' trend to meet the rising demand for sustainable food systems. With growing consumer awareness, plant-based alternatives have received considerable attention for their trend toward natural and environmentally friendly with a similar taste as animal-based foods. A study reported that the vegetarian, health-conscious consumers, and consumers with high nutritional knowledge were interested in purchasing plant-based alternatives (Kopplin and Rausch 2021). Michel, Hartmann, and Siegrist (2021) conducted an online survey with 1039 German participants to understand the consumer perception on plant-based alternatives. The survey concluded that the consumers, who frequently eat meat, were looking for meat alternatives, which were perceived similarly to their processed meat counterparts, indicating that the degree of familiarity plays a significant role in rating of meat and meat alternatives. Another consumer survey by International Food Information Council (IFIC 2020a) exclusively reported the perception of plant-based alternatives to animal meat by 1000 respondents. Many of the respondents were identified as omnivore with an interest to try plant-based alternatives to animal meat due to reduced impact on environment and overall planetary health. In comparison with the nutritional profile between animal-based beef (100% animal-based beef) and plant-based beef, 45% consumers preferred plant-based beef as healthier than animal-based beef (Figures 4A). In another survey conducted by the same research group (IFIC 2020b), 41% of consumers recommended the plant-based burger as healthier with a higher intention to buy again than a burger made from animal-based meat (Figure 4B). An Australian consumer and nutrition professional-centric study explored their attitudes to plant-based meat alternatives (Estell, Hughes, and Grafenauer 2021). Most of the consumers and nutrition professionals had tried plant-based alternatives, such as burger patties due to taste and trendy choice. The nutritional information and product claims gained the high consumer and nutrition professional attention (Estell, Hughes, and Grafenauer 2021).

A survey conducted in the UK and Italy revealed the importance and consumer perception of plant-based eggs using mapping and semantic network analysis. Product pricing strategy was one of the major influencing factors for consumers in both countries. In terms of relevance,

Figure 3. Voluntary standards for the labeling of plant-based meat alternatives issued by the Plant-Based Foods Association, San Francisco, California, United Sates of America. Certified plant-based seal (A), display of certified plant-based seal on the front of the package of Albertsons® Companies (B) and Tofurky (C) plant-based alternatives. Source: Plant-Based Foods Association (PBFA 2019).

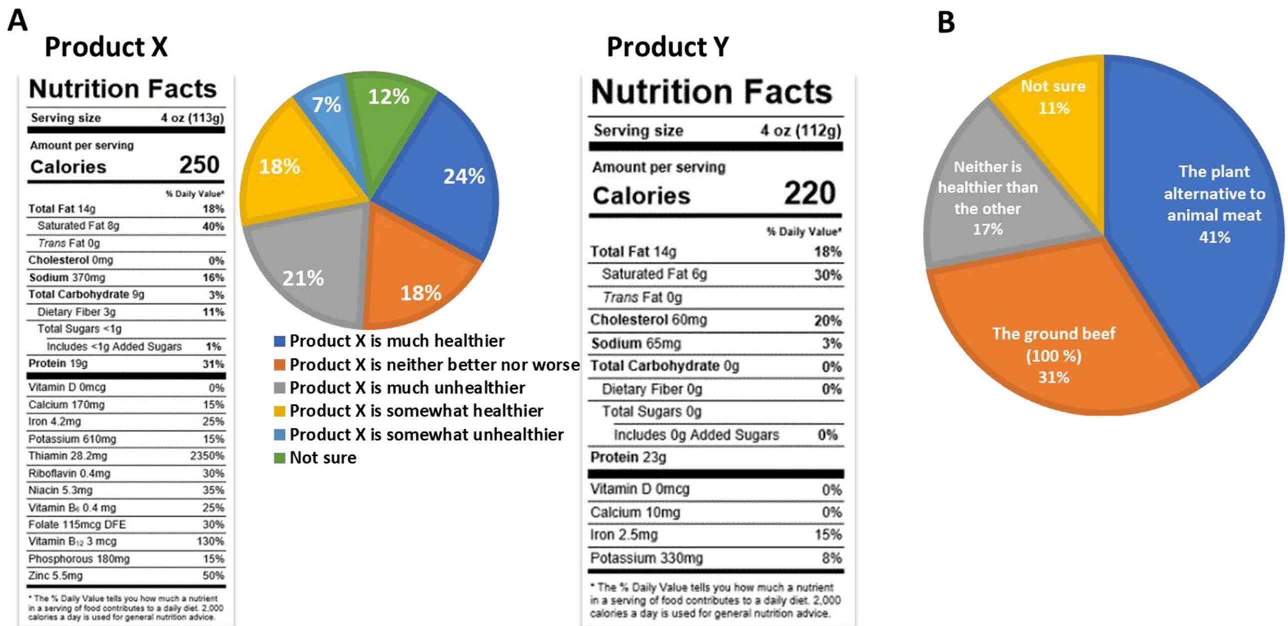


Figure 4. Consumer acceptance of plant-based alternatives. Comparison of nutritional profile of plant-based beef and animal-based beef (A) and plant-based burger to animal-based burger (B). In Figure 4A, Products X and Y indicates the plant-based and animal-based beef, respectively. Sources: International Food Information Council (IFIC 2020a, 2020b).

plant-based eggs showed positive attributes for health and environment (Rondoni et al. 2021). On the other hand, McCarthy et al. (2017) compared the consumer perception on plant-based milk alternatives and animal-based milk with 702 dairy consumers, 172 nondairy consumers, and 125 consumers of both beverages. Many respondents chose plant-based milk alternatives to consume less animal products, to counter animal mistreatment, and to protect the environment. The taste of animal-based milk was the most important attribute for plant-based beverages. Schiano et al. (2020) conducted a survey on consumer acceptability of plant-based dairy alternatives and dairy products. Many consumers selected plant-based dairy alternatives due to their intention to minimize carbon footprint/GHG emissions, indicating the sustainability in plant-based dairy alternatives. With the aim of investigating the consumer perception of plant-based milk alternatives, Prytulska et al. (2021) conducted a survey with 436 respondents. Many respondents showed interest in taking plant-based milk due to their health benefits and environmental safety. However, high pricing strategy had a significantly negative impact on consumer purchasing behavior. Based on the taste preference, many respondents preferred almond milk (20%), followed by oat milk (15%), and no preference (16%). This study concluded that the novel marketing and advertising strategies might motivate potential consumers to adopt plant-based milk alternatives. To attract wider consumer acceptability, taste and product quality of plant-based alternatives should be improved to reflect the similar sensory attributes and nutritional profile of animal-based food products. Additionally, increased demand on plant-based alternatives should motivate food processing industries for transparent and clear labeling with nutritional information and ingredients used.

Conclusions and future prospective

Growing wellness-focused customer demands and high sustainable standards are primed for plant-based meat, dairy, and seafood alternatives. Thus, food-processing industries, both startups and traditional food companies are investing significantly to create next generation plant-based alternatives. The global plant-based alternatives are a rapidly growing category and are expected to hit USD 162 billion by 2030. Although many of the plant-based alternatives imitate the mouthfeel, meat taste, structure, and texture of the animal-based foods, there are nutritional differences in plant-based meat, dairy, and seafood alternatives, which should be conquered through application of advanced food processing technologies, fermentation, fortification, and microencapsulation. Although several commercial plant-based food products are available in the market, there are still many technological and other challenges that need to be overcome to facilitate the transition to a more plant-based diet. Plant-based alternatives and animal-based foods showed differences in digestion due to their protein type, structure, and composition. The digestion and nutritional profile of plant-based alternatives should be improved through the development in ingredient selection, food quality design, processed with novel processing technologies, and fortification, which may facilitate the mimicking of nutritional profile of animal-based foods. Moreover, workplace education and government support should be needed to shift toward a more sustainable plant-based food system.

Due to the consumer demand and subsequent shift toward more plant-based alternatives that are affordable and convenient, regulatory frameworks & labeling claims should be considered to protect consumers from misleading practices of food industries. However, many countries, such as the United States, Canada, India, and China reported no specific regulatory frameworks and labeling claims for plant-based alternatives. It was also unclear for the use of words, milk, meat, and yogurt on the labeling of plant-based alternatives. Countries like the United States, Germany, and India implemented legislation prohibiting the labeling of plant-based alternatives with animal-based associated terms. The national and international agencies should draft appropriate standards to label properly the plant-based alternatives and to provide legal clarity for food business operators, which further increase the wider consumer acceptability and encourage the food processing industries for driving new creative plant-based alternatives for a healthier diet and sustainable future.

Acknowledgements

This project, MicroEncapsulation Legume prOteiNs (MELON), has received funding from the European Union's Horizon 2020 research and program under the Marie Skłodowska-Curie grant agreement No 899546.

Disclosure statement

The authors declare no conflict of interest.

References

Atalar, I. 2019. Functional kefir production from high pressure homogenized hazelnut milk. *LWT* 107:256–63. doi: 10.1016/j.lwt.2019.03.013.

Aune, D., E. Giovannucci, P. Boffetta, L. T. Fadnes, N. Keum, T. Norat, D. C. Greenwood, E. Riboli, L. J. Vatten, and S. Tonstad. 2017. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality-A systematic review and dose-response meta-analysis of prospective studies. *International Journal of Epidemiology* 46 (3):1029–56. doi: 10.1093/ije/dyw319.

Baugreet, S., C. Gomez, M. A. E. Auty, J. P. Kerry, R. M. Hamill, and A. Brodkorb. 2019. *In vitro* digestion of protein-enriched restructured beef steaks with pea protein isolate, rice protein and lentil flour following *sous vide* processing. *Innovative Food Science & Emerging Technologies* 54:152–61. doi: 10.1016/j.ifset.2019.04.005.

Bloomberg-Intelligence. 2021. Plant-based foods poised for explosive growth. https://www.bloomberg.com/professional/bi-research/?dyn=plant-based-food (Accessed 25 February, 2022).

Bonke, A., S. Sieuwerts, and I. L. Petersen. 2020. Amino acid composition of novel plant drinks from oat, lentil and pea. *Foods* 9: 429. doi: 10.3390/foods9040429.

Chen, Y., E. Capuano, and M. Stieger. 2021. Chew on it: Influence of oral processing behaviour on *in vitro* protein digestion of chicken and soya-based vegetarian chicken. *British Journal of Nutrition* 126 (9):1408–12. doi: 10.1017/S0007114520005176.

CIFST. 2020. Notice of the Chinese Institute of Food Science and Technology on the public announcement of the group standards proposed for 2020 (first report). http://www.cifst.org.cn/a/dynamic/tongzhi/20200318/1746.html (Accessed 8 January, 2022).

CJ-EU. 2017. Reference for a preliminary ruling—Common organisation of the markets in agricultural products—Regulation (EU) No 1308/2013—Article 78 and Annex VII, Part III—Decision 2010/791/EU—Definitions, designations and sales descriptions—'Milk' and 'milk products'—Designations used for the promotion and marketing of purely plant-based products. https://curia.europa.eu/juris/document/document.jsf?text=&docid=191704&pageIndex=0&doclang=EN&mode=lst&dir=&occ=first%E2%88%82=1&cid=114415 (Accessed 11 January, 2022).

Clegg, M. E., A. Tarrado Ribes, R. Reynolds, K. Kliem, and S. Stergiadis. 2021. A comparative assessment of the nutritional composition of dairy and plant-based dairy alternatives available for sale in the UK and the implications for consumers' dietary intakes. *Food Research International* 148:110586. doi: 10.1016/j.foodres.2021.110586.

Crimarco, A., S. Springfield, C. Petlura, T. Streaty, K. Cunanan, J. Lee, P. Fielding-Singh, M. M. Carter, M. A. Topf, H. C. Wastyk, et al. 2020. A randomized crossover trial on the effect of plant-based compared with animal-based meat on trimethylamine-N-oxide and cardiovascular disease risk factors in generally healthy adults: Study with appetizing plantfood—meat eating alternative trial (SWAP-MEAT). *The American Journal of Clinical Nutrition* 112 (5):1188–99. doi: 10.1093/ajcn/nqaa203.

Curtain, F., and S. Grafenauer. 2019. Plant-based meat substitutes in the flexitarian age: An audit of products on supermarket shelves. *Nutrients* 11 (11):2603. doi: 10.3390/nu11112603.

Dairy-Pride-Act. 2021. U.S. Congress. Dairy Pride Act. H.R.2828—117th Congress (2021-2022). https://www.congress.gov/bill/117th-congress/house-bill/2828?q=%7B%22search%22%3A%5B%22dairy%22%5D%7D&s=2&r=3 (Accessed 10 January, 2022).

DOPSU™. 2020. DOPSU™: Protein-powered tastiness. https://www.dopsu.com/products#No-Lamb%20Pieces (Accessed 11 January, 2022).

Dugardin, C., B. Cudennec, M. Tourret, J. Caron, L. Guérin-Deremaux, J. Behra-Miellet, C. Lefranc-Millot, and R. Ravallec. 2020. Explorative screening of bioactivities generated by plant-based proteins after *in vitro* static gastrointestinal digestion. *Nutrients* 12 (12):3746. doi: 10.3390/nu12123746.

Estell, M., J. Hughes, and S. Grafenauer. 2021. Plant protein and plant-based meat alternatives: Consumer and nutrition professional attitudes and perceptions. *Sustainability* 13 (3):1478. doi: 10.3390/su13031478.

Feng, J.-Y., K. Thakur, Z.-J. Ni, Y.-Y. Zhu, F. Hu, J.-G. Zhang, and Z.-J. Wei. 2021. Effects of okara and vitamin B_2 bioenrichment on the functional properties and *in vitro* digestion of fermented soy milk. *Food Research International* 145:110419. doi: 10.1016/j.foodres.2021.110419.

Fiorentini, M., A. J. Kinchla, and A. A. Nolden. 2020. Role of sensory evaluation in consumer acceptance of plant-based meat analogs and meat extenders: A scoping review. *Foods* 9 (9):1334. doi: 10.3390/foods9091334.

Flores, M., and J. A. Piornos. 2021. Fermented meat sausages and the challenge of their plant-based alternatives: A comparative review on aroma-related aspects. *Meat Science* 182:108636. doi: 10.1016/j.meatsci.2021.108636.

FSSAI. 2020. Food Safety and Standards (food products standards and food additives) amendment regulations, 2020. https://www.fssai.gov.in/upload/uploadfiles/files/Draft_Notification_Dairy_Analogue_30_07_2020.pdf (Accessed 7 January, 2022).

GFI_{SM}. 2021a. Overall plant-based food market. https://gfi.org/market-research/ (Accessed 12 February, 2022).

GFI_{SM}. 2021b. Alternative protein company database. https://gfi.org/resource/alternative-protein-company-database/ (Accessed 14 February, 2022).

GFI_{SM}. 2021c. Alternative protein research grants. https://gfi.org/researchgrants/ (Accessed 21 February, 2022).

Good®Catch. 2021. Frozen plant-based crab cakes (breaded). https://goodcatchfoods.com/our-products/ (Accessed 18 January, 2022).

Grasso, N., L. Alonso-Miravalles, and J. A. O'Mahony. 2020. Composition, physicochemical and sensorial properties of commercial plant-based yogurts. *Foods* 9 (3):252. doi: 10.3390/foods9030252.

Grasso, N., Y. H. Roos, S. V. Crowley, E. K. Arendt, and J. A. O'Mahony. 2021. Composition and physicochemical properties of commercial plant-based block-style products as alternatives to cheese. *Future Foods* 4:100048. doi: 10.1016/j.fufo.2021.100048.

Greis, M., T. Sainio, K. Katina, A. J. Kinchla, A. Nolden, R. Partanen, and L. Seppä. 2020. Dynamic texture perception in plant-based yogurt alternatives: Identifying temporal drivers of liking by TDS.

Food Quality and Preference 86:104019. doi: 10.1016/j.foodqual.2020.104019.

Hadi, J., and G. Brightwell. 2021. Safety of alternative proteins: Technological, environmental and regulatory aspects of cultured meat, plant-based meat, insect protein and single-cell protein. *Foods* 10 (6):1226. doi: 10.3390/foods10061226.

Harnack, L., S. Mork, S. Valluri, C. Weber, K. Schmitz, J. Stevenson, and J. Pettit. 2021. Nutrient composition of a selection of plant-based ground beef alternative products available in the United States. *Journal of the Academy of Nutrition and Dietetics* 121: (12):2401–8.e12. doi: 10.1016/j.jand.2021.05.002.

He, J., N. M. Evans, H. Liu, and S. Shao. 2020. A review of research on plant-based meat alternatives: Driving forces, history, manufacturing, and consumer attitudes. *Comprehensive Reviews in Food Science and Food Safety* 19 (5):2639–56. doi: 10.1111/1541-4337.12610.

IFIC. 2020a. A consumer survey on plant alternatives to animal meat. https://foodinsight.org/ (Accessed 18 January, 2022).

IFIC. 2020b. A consumer survey on plant alternatives to animal meat 2.0. https://foodinsight.org/ (Accessed 18 January, 2022).

James, S., L. Nwokocha, B. Tsebam, S. Amuga, A. Ibrahim, and Y. Audu. 2016. Effects of different coagulants on the physico-chemical, microbial and sensory properties of Wara, a Nigerian soft soy-cheese. *Journal of Tropical Agriculture, Food, Environment and Extension* 15:41–5. doi: 10.4314/as.v15i3.7.

Karovičová, J., Z. Kohajdová, L. Minarovičová, M. Lauková, M. Greifová, G. Greif, and J. Hojerová. 2020. Utilisation of quinoa for development of fermented beverages. *Potravinarstvo Slovak Journal of Food Sciences* 14:465–72. doi: 10.5219/1323.

Kazir, M., and Y. D. Livney. 2021. Plant-based seafood analogs. *Molecules* 26 (6):1559. doi: 10.3390/molecules26061559.

Kerry. 2020. Winning with plant-based-unlocking the keys to success for a growing market: Proprietary consumer research. https://www.kerry.com/ (Accessed 14 January, 2022).

Kim, H., C. M. Rebholz, S. Hegde, C. LaFiura, M. Raghavan, J. F. Lloyd, S. Cheng, and S. B. Seidelmann. 2021. Plant-based diets, pescatarian diets and COVID-19 severity: A population-based case-control study in six countries. *BMJ Nutrition, Prevention & Health* 4 (1):257–66. doi: 10.1136/bmjnph-2021-000272.

Kopplin, C. S., and T. M. Rausch. 2021. Above and beyond meat: The role of consumers' dietary behavior for the purchase of plant-based food substitutes. *Review of Managerial Science*. 1–30. doi: 10.1007/s11846-021-00480-x.

Krause, A. J., and K. A. Williams. Sr. 2019, May-Jun. Understanding and adopting plant-based nutrition: A survey of medical providers. *American Journal of Lifestyle Medicine* 13 (3):312–8. doi: 10.1177/1559827617703592.

Kundu, P., J. Dhankhar, and A. Sharma. 2018. Development of non dairy milk alternative using soymilk and almond milk. *Current Research in Nutrition and Food Science Journal* 6 (1):203–10. doi: 10.12944/CRNFSJ.6.1.23.

Kyriakopoulou, K., J. K. Keppler, and A. J. van der Goot. 2021. Functionality of ingredients and additives in plant-based meat analogues. *Foods* 10 (3):600. doi: 10.3390/foods10030600.

Lacour, C., L. Seconda, B. Allès, S. Hercberg, B. Langevin, P. Pointereau, D. Lairon, J. Baudry, and E. Kesse-Guyot. 2018. Environmental impacts of plant-based diets: How does organic food consumption contribute to environmental sustainability? *Frontiers in Nutrition* 5:8–13. doi: 10.3389/fnut.2018.00008.

Leialohilani, A., and A. de Boer. 2020. EU food legislation impacts innovation in the area of plant-based dairy alternatives. *Trends in Food Science & Technology* 104:262–7. doi: 10.1016/j.tifs.2020.07.021.

Levy, R., Z. Okun, M. Davidovich-Pinhas, and A. Shpigelman. 2021. Utilization of high-pressure homogenization of potato protein isolate for the production of dairy-free yogurt-like fermented product. *Food Hydrocolloids* 113:106442. doi: 10.1016/j.foodhyd.2020.106442.

Lin, Q., L. Pan, N. Deng, M. Sang, K. Cai, C. Chen, J. Han, and A. Ye. 2022. Protein digestibility of textured-wheat-protein (TWP) -based meat analogues: (I) Effects of fibrous structure. *Food Hydrocolloids* 130:107694. doi: 10.1016/j.foodhyd.2022.107694.

Lonkila, A., and M. Kaljonen. 2021. Promises of meat and milk alternatives: An integrative literature review on emergent research themes. *Agriculture and Human Values* 38 (3):625–39. doi: 10.1007/s10460-020-10184-9.

Lopes, M., C. Pierrepont, C. M. Duarte, A. Filipe, B. Medronho, and I. Sousa. 2020. Legume beverages from chickpea and lupin, as new milk alternatives. *Foods* 9 (10):1458. doi: 10.3390/foods9101458.

López-Salas, L., I. Borrás-Linares, D. Quintin, P. García-Gomez, R. Giménez-Martínez, A. Segura-Carretero, and J. Lozano-Sánchez. 2021. Artichoke by-products as natural source of phenolic food ingredient. *Applied Sciences* 11 (9):3788. doi: 10.3390/app11093788.

Łopusiewicz, Ł., E. Drozłowska, P. Siedlecka, M. Mężyńska, A. Bartkowiak, M. Sienkiewicz, H. Zielińska-Bliźniewska, and P. Kwiatkowski. 2019. Development, characterization, and bioactivity of non-dairy kefir-like fermented beverage based on flaxseed oil cake. *Foods* 8 (11):544. doi: 10.3390/foods8110544.

Lusk, J. L., D. Blaustein-Rejto, S. Shah, and G. T. Tonsor. 2022. Impact of plant-based meat alternatives on cattle inventories and greenhouse gas emissions. *Environmental Research Letters* 17:024035. doi: 10.1088/1748-9326/ac4fda.

Martínez-Padilla, E., K. Li, H. Blok Frandsen, M. Skejovic Joehnke, E. Vargas-Bello-Pérez, and I. L. Petersen. 2020. *In vitro* protein digestibility and fatty acid profile of commercial plant-based milk alternatives. *Foods* 9 (12):1784. doi: 10.3390/foods9121784.

Mattice, K. D., and A. G. Marangoni. 2020. Physical properties of plant-based cheese products produced with zein. *Food Hydrocolloids* 105:105746. doi: 10.1016/j.foodhyd.2020.105746.

McCarthy, K. S., M. Parker, A. Ameerally, S. L. Drake, and M. A. Drake. 2017. Drivers of choice for fluid milk versus plant-based alternatives: What are consumer perceptions of fluid milk? *Journal of Dairy Science* 100 (8):6125–38. doi: 10.3168/jds.2016-12519.

McClements, D. J. 2020. Future foods: Is it possible to design a healthier and more sustainable food supply? *Nutrition Bulletin* 45 (3):341–54. doi: 10.1111/nbu.12457.

McClements, D. J., and L. Grossmann. 2021. The science of plant-based foods: Constructing next-generation meat, fish, milk, and egg analogs. *Comprehensive Reviews in Food Science and Food Safety* 20 (4):4049–100. doi: 10.1111/1541-4337.12771.

McClements, D. J., E. Newman, and I. F. McClements. 2019. Plant-based milks: A review of the science underpinning their design, fabrication, and performance. *Comprehensive Reviews in Food Science and Food Safety* 18 (6):2047–67. doi: 10.1111/1541-4337.12505.

McClements, D. J., J. Weiss, A. J. Kinchla, A. A. Nolden, and L. Grossmann. 2021. Methods for testing the quality attributes of plant-based foods: Meat- and processed-meat analogs. *Foods. Foods* 10 (2):260. doi: 10.3390/foods10020260.

Michel, F., C. Hartmann, and M. Siegrist. 2021. Consumers' associations, perceptions and acceptance of meat and plant-based meat alternatives. *Food Quality and Preference* 87:104063. doi: 10.1016/j.foodqual.2020.104063.

MovingMountains®. 2020a. Moving Mountains® Launches UK's first plant-based sausage burger in Sainsbury's. https://movingmountainsfoods.com/moving-mountains-launches-uks-first-plant-based-sausage-burger-in-sainsburys/ (Accessed 11 January, 2022).

MovingMountains®. 2020b. There's not enough fish in the sea – Moving Mountains® Cause a splash with launch of plant-based fish fingers. https://movingmountainsfoods.com/moving-mountains-launch-plant-based-fish-fingers/ (Accessed 22 January, 2022).

MovingMountains®. 2021. Moving Mountains® launches plant-based fish fillet so brits can enjoy the ultimate plant-based fish & chips. https://movingmountainsfoods.com/moving-mountains-launches-plant-based-fish-fillet-so-brits-can-enjoy-the-ultimate-plant-based-fish-chips/ (Accessed 22 January, 2022).

Musa-Veloso, K., and J. Juana. 2020. Regulation and labeling of plant-based beverages and simulated meat, poultry, and egg products in Canada and the United States. *Cereal Foods World* 65 (4):1–13. doi: 10.1094/CFW-65-4-0044.

National-Law-Review. 2020. Plant-based foods: Exciting technology, but don't overlook the regulatory considerations. https://www.natlawreview.com/article/plant-based-foods-exciting-technology-don-t-overlook-regulatory-considerations (Accessed 11 January, 2022).

New-Wave-Foods®. 2021. Plant-based new wave shrimp®. https://www.newwavefoods.com/foodservice/products/ (Accessed 12 January, 2022).

Ocean-Hunger-Foods®. 2021. Ocean-Hunger-Foods®. https://oceanhungerfoods.com/ (Acessed 14 January, 2022).

OmniFoods®. 2018. OmniPork: All purpose and plant-based pork. https://omnifoods.co/tw-en/product/15 (Accessed 12 January, 2022).

Pachekrepapol, U., Y. Kokhuenkhan, and J. Ongsawat. 2021. Formulation of yogurt-like product from coconut milk and evaluation of physicochemical, rheological, and sensory properties. *International Journal of Gastronomy and Food Science* 25:100393. doi: 10.1016/j.ijgfs.2021.100393.

Packaged-Facts. 2020. Plant-based market has opportunity with prepared meals. https://www.packagedfacts.com/ (Accessed 14 January, 2022).

PBFA. 2019. Voluntary standards for the labeling of meat alternatives in the United States. https://www.plantbasedfoods.org/wp-content/uploads/PBFA-Labeling-Standards-for-Meat-Alternatives.pdf (Accessed 11 January, 2022).

Pointke, M., and E. Pawelzik. 2022. Plant-based alternative products: Are they healthy alternatives? micro- and macronutrients and nutritional scoring. *Nutrients* 14 (3):601. doi: 10.3390/nu14030601.

Prytulska, N., I. Motuzka, A. Koshelnyk, O. Motuzka, L. Yashchenko, M. Jarossová, P. Krnáčová, J. Wyka, E. Malczyk, and M. Habánová. 2021. Consumer preferences on the market of plant-based milk analogues. *Potravinarstvo Slovak Journal of Food Sciences* 15:131–42. doi: 10.5219/1485.

Quorn™. 2020. Quorn™ vegan fishless fingers. https://www.quorn.co.uk/products/vegan-fishless-fingers#productInformation (Accessed 20 January, 2022).

Rahmatuzzaman Rana, M., M. Babor, and A. A. Sabuz. 2021. Traceability of sweeteners in soy yogurt using linear discriminant analysis of physicochemical and sensory parameters. *Journal of Agriculture and Food Research* 5:100155. doi: 10.1016/j.jafr.2021.100155.

Real-MEAT-Act. 2019. U.S. Congress. Real marketing edible artificials truthfully act of 2019. S.3016—116th Congress, 2019-2020, 1st Session. https://www.congress.gov/bill/116th-congress/senate-bill/3016/text (Accessed 7 January, 2022).

Rincon, L., R. Braz Assunção Botelho, and E. R. de Alencar. 2020. Development of novel plant-based milk based on chickpea and coconut. *LWT* 128:109479. doi: 10.1016/j.lwt.2020.109479.

Rischer, H., G. R. Szilvay, and K.-M. Oksman-Caldentey. 2020. Cellular agriculture: Industrial biotechnology for food and materials. *Current Opinion in Biotechnology* 61:128–34. doi: 10.1016/j.copbio.2019.12.003.

Rondoni, A., C. Grebitus, E. Millan, and D. Asioli. 2021. Exploring consumers' perceptions of plant-based eggs using concept mapping and semantic network analysis. *Food Quality and Preference* 94:104327. doi: 10.1016/j.foodqual.2021.104327.

Santo, R. E., B. F. Kim, S. E. Goldman, J. Dutkiewicz, E. M. B. Biehl, M. W. Bloem, R. A. Neff, and K. E. Nachman. 2020. Considering plant-based meat substitutes and cell-based meats: A public health and food systems perspective. *Frontiers in Nutrition* 4:134. doi: 10.3389/fsufs.2020.00134.

Schiano, A. N., W. S. Harwood, P. D. Gerard, and M. A. Drake. 2020. Consumer perception of the sustainability of dairy products and plant-based dairy alternatives. *Journal of Dairy Science* 103 (12):11228–43. doi: 10.3168/jds.2020-18406.

Sethi, S., S. K. Tyagi, and R. K. Anurag. 2016. Plant-based milk alternatives an emerging segment of functional beverages: A review. *Journal of Food Science and Technology* 53 (9):3408–23. doi: 10.1007/s13197-016-2328-3.

Silva, J. G. S., A. P. Rebellato, E. T. d S. Caramês, R. Greiner, and J. A. L. Pallone. 2020. *In vitro* digestion effect on mineral bioaccessibility and antioxidant bioactive compounds of plant-based beverages. *Food Research International (Ottawa, Ont.)* 130:108993. doi: 10.1016/j.foodres.2020.108993.

Sim, S. Y. J., X. Y. Hua, and C. J. Henry. 2020. A novel approach to structure plant-based yogurts using high pressure processing. *Foods* 9 (8):1126. doi: 10.3390/foods9081126.

Smetana, S., A. Profeta, R. Voigt, C. Kircher, and V. Heinz. 2021. Meat substitution in burgers: Nutritional scoring, sensorial testing, and life cycle assessment. *Future Foods* 4:100042. doi: 10.1016/j.fufo.2021.100042.

Swing, C. J., T. W. Thompson, O. Guimaraes, I. Geornaras, T. E. Engle, K. E. Belk, C. L. Gifford, M. N. Nair, L. Suriati, and I. S. Utama. 2021. Nutritional composition of novel plant-based meat alternatives and traditional animal-based meats. *HSOA Journal of Food Science & Nutrition* 7:2. doi: 10.24966/FSN-1076/100109.

Tangyu, M., J. Muller, C. J. Bolten, and C. Wittmann. 2019. Fermentation of plant-based milk alternatives for improved flavour and nutritional value. *Applied Microbiology and Biotechnology* 103 (23-24):9263–75. doi: 10.1007/s00253-019-10175-9.

Technomic. 2020. Generational consumer trend report. https://www.technomic.com/reports/consumer/consumer-trend-reports/generational (Accessed 20 February, 2021).

UN. 2017. United Nations: World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. Department of economic and social affairs. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html (Accessed 24 January, 2021).

van Dijk, M., T. Morley, M. L. Rau, and Y. Saghai. 2021. A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food* 2 (7):494–501. doi: 10.1038/s43016-021-00322-9.

van Vliet, S., J. R. Bain, M. J. Muehlbauer, F. D. Provenza, S. L. Kronberg, C. F. Pieper, and K. M. Huffman. 2021. A metabolomics comparison of plant-based meat and grass-fed meat indicates large nutritional differences despite comparable nutrition facts panels. *Scientific Reports* 11 (1):13828. doi: 10.1038/s41598-021-93100-3.

Verni, M., C. Demarinis, C. G. Rizzello, and F. Baruzzi. 2020. Design and characterization of a novel fermented beverage from lentil grains. *Foods* 9 (7):893. doi: 10.3390/foods9070893.

V™Bites. 2020. Plant-based fish. https://www.vbites.com/shop/fish-alternatives/ (Accessed 15 January, 2022).

Wang, X., A. Ye, A. Dave, and H. Singh. 2021. *In vitro* digestion of soymilk using a human gastric simulator: Impact of structural changes on kinetics of release of proteins and lipids. *Food Hydrocolloids* 111:106235. doi: 10.1016/j.foodhyd.2020.106235.

Yang, M., N. Li, L. Tong, B. Fan, L. Wang, F. Wang, and L. Liu. 2021. Comparison of physicochemical properties and volatile flavor compounds of pea protein and mung bean protein-based yogurt. *LWT* 152:112390. doi: 10.1016/j.lwt.2021.112390.

Zhang, T., W. Dou, X. Zhang, Y. Zhao, Y. Zhang, L. Jiang, and X. Sui. 2021. The development history and recent updates on soy protein-based meat alternatives. *Trends in Food Science & Technology* 109:702–10. doi: 10.1016/j.tifs.2021.01.060.

Zheng, B., H. Zhou, and D. J. McClements. 2021. Nutraceutical-fortified plant-based milk analogs: Bioaccessibility of curcumin-loaded almond, cashew, coconut, and oat milks. *LWT* 147:111517. doi: 10.1016/j.lwt.2021.111517.

Zhou, H., Y. Hu, Y. Tan, Z. Zhang, and D. J. McClements. 2021. Digestibility and gastrointestinal fate of meat *versus* plant-based meat analogs: An *in vitro* comparison. *Food Chemistry* 364:130439. doi: 10.1016/j.foodchem.2021.130439.

Zhou, H., J. Liu, T. Dai, J. L. Muriel Mundo, Y. Tan, L. Bai, and D. J. McClements. 2021. The gastrointestinal fate of inorganic and organic nanoparticles in vitamin D-fortified plant-based milks. *Food Hydrocolloids* 112:106310. doi: 10.1016/j.foodhyd.2020.106310.

Zhou, H., B. Zheng, Z. Zhang, R. Zhang, L. He, and D. J. McClements. 2021. Fortification of plant-based milk with calcium may reduce vitamin D bioaccessibility: An *in vitro* digestion study. *Journal of Agricultural and Food Chemistry* 69 (14):4223–33. doi: 10.1021/acs.jafc.1c01525.