Navigating Plant-Based Meat Analogues: Challenges and Strategies for Consumer Acceptance

Abstract:

The emergence of plant-based meat analogues (PBMA) offers a promising pathway to address the environmental and health challenges associated with traditional meat consumption. However, the transition from meat to PBMA faces significant hurdles in gaining consumer acceptance. This comprehensive review examines the challenges and strategies essential for the success of PBMA in the consumer market.Consumer attitudes towards PBMA are influenced by factors such as texture, taste, education, income, and social influence. The majority of consumers, particularly non-vegetarians, remain reluctant to fully embrace PBMA, highlighting the need for PBMA products to closely resemble traditional meat in sensory attributes. Education and awareness campaigns are critical in familiarizing consumers with PBMA's potential health and environmental benefits. Furthermore, product development should encompass consumer preferences and convenience-related aspects, while efforts to gradually reduce global meat consumption are essential. The global shift towards reduced meat consumption, driven by health consciousness and environmental concerns, presents an opportunity for PBMA. Targeting non-meat eaters, higher-income groups, the younger demographic, and educated individuals can foster greater acceptance. Overall, aligning product quality, consumer education, and innovation is pivotal for bridging the gap between consumer preferences and PBMA offerings.

Keywords: Plant-based meat analogues, Consumer attitude, Consumer acceptance, Nutrition, Challenges, Safety

Introduction

Plant-based meat analogues (PBMA), engineered to emulate the nutritional composition and sensory attributes of traditional meat products, have recently emerged as prominent additions to the culinary landscape. These innovative food items represent a promising solution to address the environmental challenges associated with conventional meat production. According to Egbert and Borders (2006), a typical meat analogue comprises water (50-80%), textured vegetable proteins (10-25%), non-textured proteins (4-20%), flavourings (3-10%), fat (0-15%), binding agents (1-5%), and colouring agents (0-0.5%). The development of PBMA that efficiently fulfil nutrient requirements, including essential elements like copper, iron, manganese, thiamin, and β-carotene, through plant-based sources offers a potential reduction in environmental hazards, particularly in terms of greenhouse gas emissions, when compared to their animal-derived counterparts (Eshel *et al.,* 2019). Gonzalez *et al.* (2011) have also emphasized the potential of judiciously selecting plant-based sources to provide substantial amounts of protein, vitamin A, and iron with a reduced carbon footprint, relative to animal sources. Notably, novel PBMA products like the Impossible

Comment [L1]: Review articles should use a method, for example using Bibliometrics. For this reason, it is recommended to add a review article method subsection.

Comment [L2]: Abstract need to be explored more to better describe the contents of the manuscript. Abstract and contents of manuscripts do not match.

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Burger and Beyond Burger have garnered widespread popularity, substantial financial investments, media attention and scientific interest (Van Vliet *et al.,* 2020).

While PBMA offers an intriguing alternative to traditional meat, it is essential to acknowledge that their nutritive value may differ from whole, minimally processed plant-based foods, which typically retain maximum nutrient content. Nevertheless, the nutritional profile of PBMA can be enhanced by incorporating health-promoting ingredients to create a final product that meets dietary standards. Certain nutrients are readily available in conventional meat, whereas others are more abundant in plant-based sources. For instance, magnesium and ascorbic acid are more abundant in plants than in red meat. Additionally, plant-based foods exhibit higher levels of nutrients such as folate, manganese, thiamin, potassium and vitamin E (Davey *et al*., 2003). In contrast, long-chain polyunsaturated fatty acids (e.g., docosahexaenoic acid and eicosapentaenoic acid), vitamin A (retinol), B12 (adenosyl and hydroxycobalamin), D (cholecalciferol), vitamin E, K2 (menaquinone-4), and essential minerals like iron and zinc are predominantly sourced from animal-based diets, setting them apart from plant-based alternatives (Van Vliet *et al.,* 2018).

The quality of dietary proteins is typically assessed using two key criteria: the protein digestibility-corrected amino acid score (PDCAAS) and the digestible indispensable amino acid score (DIAAS). One notable challenge associated with PBMA is the presence of a diverse array of phytochemicals, some of which may have adverse effects on consumer health. According to Van Vliet *et al.* (2020), animal proteins often exhibit higher scores (>0.9) in PDCAAS and DIAAS, while plant proteins fall within a range of 0.4 to 0.9. This discrepancy may be attributed to reduced digestibility due to the presence of anti-nutrients such as trypsin and phytate inhibitors, as highlighted by Gilani *et al.* (2012). In addressing this concern, Hodgkinson *et al.* (2018) recommend the utilization of purified protein sources, which contain fewer anti-nutritional factors, thereby yielding PDCAAS and DIAAS scores comparable to meat proteins. Consequently, the incorporation of concentrates or isolates of plant proteins like soy, pea, and other sources in PBMA production offers a potential solution.

To further enhance the amino acid profile and nutritional balance of PBMA, Van Vliet *et al.* (2015) propose a combination of plant proteins with varying methionine and lysine content. This approach involves using plant proteins with higher methionine and lower lysine content (e.g., hemp, rice, wheat, and maize flour) in conjunction with those exhibiting lower methionine and higher lysine content (e.g., soy and pea protein concentrates). Such formulations aim to address the challenge of achieving a balanced amino acid composition in PBMA, thereby optimising their nutritional value.

In light of these considerations, this review paper explores the multifaceted aspects of plant-based meat analogues, encompassing their nutritional profiles, environmental implications, and strategies for enhancing their nutritive value and overall quality. By delving into these key facets, we aim to provide valuable insights into the burgeoning field of PBMA, shedding light on their potential as sustainable and nutritionally sound alternatives to traditional meat products.

Global market

In the global context, the consumption of meat and meat products is steadily on the rise, and with an anticipated world population of 9.7 billion by 2050 (United Nations, 2019), there is a growing need for increased animal production. However, this escalation in animal production is poised to have adverse consequences on our environment, manifesting in increased greenhouse gas (GHG) emissions, greater utilization of water and other resources, eutrophication, and deforestation (Crippa *et al.,* 2021; Huang *et al*., 2022). The demand for animal-based proteins on a global scale is projected to surge and may not be consistently met, necessitating a fundamental transformation in the existing food production and supply system (De Angelis *et al*., 2020). Curtainand Grafenauer (2019) conducted a comprehensive study comparing dietary guidelines from approximately 90 countries and discovered that 37% of these guidelines recommend vegetable proteins as a viable alternative to meat proteins.

The highest share of the global Plant-Based Meat Analogues (PBMA) market is currently held by Europe, accounting for 51.5% of the market, followed by North America (26.8%), Asia Pacific (11.8%), Latin America (6.3%), and the Middle East and Africa (3.6%) (Boukid, 2021). Notably, a survey conducted by the Good Food Institute identified the top-selling PBMA products in 2019, with burgers leading at USD 283 million in sales, followed by sausages and hot dogs at USD 159 million, and patties at USD 120 million (Ahmad *et al*., 2022).

Recent research conducted by the Custom Market Insight Market (2023) research team indicates a projected compound annual growth rate (CAGR) of 42.1% for the global meat alternative market from 2023 to 2030. In 2023, the market size is anticipated to reach USD 10.1 billion, with an expected valuation of USD 233.87 billion by 2030. According to Zion Market Research (2019), the global PBMA market was estimated to be approximately USD 11.92 billion in 2018 and is poised to reach around USD 21.23 billion by 2025, experiencing a CAGR of approximately 8.6% between 2019 and 2025.

Furthermore, the global meat alternative market analysis conducted for the forecast period (2018-2028) by Mordan Intelligence Report (2019) predicts a CAGR of 10.85% for the global meat alternative market. Among meat substitutes, Textured Vegetable Protein (TVP), derived exclusively from soy, wheat and peas, has gained widespread popularity as a functional and nutritious alternative to meat. The trade value of TVP has shown remarkable growth, with a 34.44% increase from 2016 to 2021. Leading TVP-producing companies such as Archer Daniels Midland, Cargill, Ingredion Incorporated, and Kerry Group are collaborating with PBMA manufacturers like Beyond Meat, Eat Just, Gardein, Impossible Foods, and Quorn to expand their market share.

Despite the economic challenges posed by the COVID-19 pandemic, the consumption of meat alternatives witnessed an 11.96% increase in 2020, underscoring the growing interest in healthier dietary choices. Post-pandemic, manufacturers of meat alternatives reported record-breaking sales as consumers explored healthier options. The Asia-Pacific meat substitutes market is projected to achieve a CAGR of 13.53% during the forecast period (2018-2028), with China leading in meat alternative consumption, followed by India and Japan. India, in particular, is emerging as a significant player in the Asia-Pacific region, with an expected CAGR of 14.85% during the forecast period (2022-2028). In the Indian meat substitutes market, the top five companies hold an 8.58% market share, with notable players including Ahimsa Food, GoodDot Enterprises Private Limited, Impossible Foods, Imagine Foods Private Limited, and Morinaga Milk Industry.

Looking ahead, the Middle East and Africa meat substitute products market is anticipated to achieve a CAGR of 8.64% during the forecast period (2020-2025), while the United States meat substitutes market is poised for a CAGR of 9.83% (2016-2028). The United States meat substitutes market exhibits consolidation, with the top five companies collectively owning 55.16% of the market. Key players in this market include Beyond Meat, Amy's Kitchen, Impossible Foods, Conagra Brands Incorporated, and The Kellogg Company. Additionally, the North American meat substitutes market is expected to experience a CAGR of 9.54% (2018-2028).

These trends and market projections underscore the growing significance of meat alternatives, particularly PBMA, in the evolving global food landscape as consumers increasingly seek sustainable and nutritious alternatives to traditional meat products.

Composition of plant-based meat analogues

A typical plant-based meat analogue (PBMA) formulation comprises a substantial composition of essential components, including water, proteins in both textured and non-textured formats, oils and fats, flavour enhancers, flavourings, binding agents and colouring agents. Egbert and Borders (2006) provide a comprehensive breakdown of the composition of a meat analogue, outlining the percentages of key constituents, which typically include water (50-80%), textured vegetable proteins (10-25%), non-textured proteins (4-20%), oils and fats (0-15%), binding agents (1-5%), flavouring agents (3-10%) and colouring agents (0-0.5%). Innovative developments in PBMA necessitate a deep understanding of the individual functions of these ingredients and their interactions. This knowledge is crucial for the creation of alternatives that not only align with consumer preferences but also advance the trend of reducing the reliance on highly processed components. The quest for minimizing the use of processed ingredients in PBMA formulations is gaining momentum in recent years, reflecting a shift towards more wholesome and consumer-friendly plant-based meat products.

List 1 :Summary of research papers on PBMA, type of products, ingredients mentioned and methods adopted for preparation

Type of Product	Ingredients mentioned	Method adopted	References
Meat analogue extrudates	Oat and pea protein blends at ratios 20:80, 30:70, 50:50, and 70:30	Extrusion	Kaleda *et al.* (2021)
PBMA patties	Lactoferrin, red yeast rice, isolated soy protein, isolated pea protein, texturized vegetable protein, methylcellulose, starch, gelatin, coconut oil, molasses, canola oil, and yeast extract.	Mixing protein with hydrocolloids	Bakhsh *et al.* (2022)
Impossible	Water, Textured Wheat Protein, Coconut Oil,	Extrusion	Swing *et al.* (2021)

foods burger	Potato Protein, Natural Flavors, 2% or less of Leghemoglobin (Soy), Yeast Extract, Salt, Konjac Gum, Xanthan Gum, Soy Protein Isolate, Thiamin, Riboflavin, Zinc, Niacin, Vitamin B6, Vitamin B12, Vitamin C and Vitamin E.		
Beyond meat burger	Water, Pea Protein, Expeller-Pressed Canola Oil, Refined Coconut Oil, Rice Protein, Natural Flavors, Cocoa Butter, Mung Bean Protein, Methylcellulose, Potato Starch, Apple Extract, Pomegranate Extract, Salt, Potassium Chloride, Vinegar, Lemon Juice, Sunflower Lecithin, Beetroot Juice Extract.	Extrusion	Swing *et al.* (2021)
Plant-based burger	Texturized soy, peanut flour, chia gelled emulsion, pea fibre, salt, spices, beetroot juice.	Mixing protein with hydrocolloids	Botella-Martinez *et al.* (2022)
PBMA batter	Wheat gluten and soy protein (at the ratio of 100:0, 80:20, 60:40 and 40:60 % w/w dry protein basis), soybean oil, wheat starch, all-in-one seasoning	Mechanical elongation method	Chiang *et al.* (2021)
Extruded meat analogues	Soy protein concentrate, wheat gluten, wheat starch.	Extrusion	Chiang *et al.* (2019)
Fibrous meat analogues	Oat fibre concentrate, pea protein isolate	Extrusion	Diaz *et al.* (2022)
Meat analogue	Wheat gluten, pea protein isolate with xanthan or iota-carrageenan or sodium alginate or guar gum or carboxymethyl cellulose or low acyl gellan gum or low methylated pectin or locust bean gum at three concentrations (1%, 2% and 3%)	High-temperature shear cell	Dinani*et al.* (2023a)
Meat analogue	Pea protein isolate, wheat gluten, L- cysteine, L-ascorbic acid.	High-temperature shear cell	Dinani*et al.* (2023b)
Meat analogue	Faba bean protein concentrate	Extrusion	Do Carmo *et al.* (2021)
Plant-based salami analogue	Soy protein isolate, sal fat, canola oil, glucano – delta-lactone, salami aroma, wheat gluten, beetroot powder, powdered bell pepper, spices, salt	Mixing protein with hydrocolloids	Dreher *et al.* (2021)
Plant-protein extrudates	Wheat gluten, pea protein isolate, rice protein isolate, pea protein concentrate	Extrusion	Nisov*et al.* (2022)
Plant-based nugget	Pea protein isolate, Wheat gluten, potato starch, vegetable oil, methylcellulose, baking powder, salt, calcium chloride	Mixing protein with hydrocolloids	Yuliarthi*et al.* (2021)
Plant-based patty	Jack fruit, wheat gluten, starch, soy protein, vegetable oil, mushroom seasoning and spices	Mixing protein with hydrocolloids	Hamid *et al.* (2020)
Meat analogue	Wheat gluten, rice protein concentrate, soy protein concentrate, salt	High-temperature shear cell	Jia *et al.* (2021)
Meat analogue	Wheat gluten, rice protein isolate, soy protein isolate, corn starch	Extrusion	Lee *et al.* (2022)
Soy protein-	Soy protein isolate (25.9%), wheat gluten	Mixing protein	Jung *et al.* (2022)

based meat analogue	(13.0%), corn starch (1.9%), methylcellulose (0.9%), red beet powder (1.3%), soybean oil (0.9%), salt (0.5%), and distilled water (55.6%).	with hydrocolloids	
Extruded meat analogue	Oat protein concentrate, pea protein isolate	Extrusion	Kaleda *et al.* (2020)
Plant-based patty	Texturized vegetable protein, methylcellulose, molasses, yeast seasoning, umami seasoning, coconut oil, canola oil, garlic powder, and black pepper	Mixing protein with hydrocolloids	Bakhsh *et al.* (2021)
Plant-based meat analogue patty	Textured vegetable protein (soy protein), palm oil, canola oil, methylcellulose, apple extract, and salt. Commercial natural pigments from red beet, monascus red, sorghum, cacao	Mixing protein with hydrocolloids	Ryu *et al.* (2023)
Plant-based meat analogue	Textured vegetable protein, olive oil, methylcellulose	Mixing protein with hydrocolloids	Sakai *et al.* (2021)
Meat analogue	Macuna bean flour	Extrusion	Omihimi*et al.* (2014)
Meat analogue	Lupin protein isolate, lupin protein concentrate, carrageenan, spirulina biomass	Extrusion	Palanisamy *et al.* (2019)
Hybrid meat extrudates	Pea protein concentrate, pea protein isolate	Extrusion	Pori *et al.* (2023)
Meat analogue	Fermented or hydrolyzed soy press cake (10%), textured wheat protein (25%) with a protein content of 75%, sunflower oil (12%), coconut oil (8.0%), modified starch (2.5%), salt composition (2.0%), oat flakes (2.0%), maltodextrin (1.3%), soluble Fibregum B acacia (0.5%), and methylcellulose (0.4%), water (46.7%).	Mixing protein with hydrocolloids	Razavizadeh*et al.* (2022)
Fibrous meat analogue	Pea protein concentrate, pea protein isolate, oat bran, wheat bran	Extrusion	Rekola *et al.* (2023)
Plant protein-based meat analogue	Isolated soy protein, isolated mung bean protein, isolated peanut protein, isolated pea protein, and wheat gluten.	Extrusion	Samard and Ryu (2019)
Plant-based patty	Texturized soy, shiitake mushroom, nutritional yeast extract, chickpea protein, wheat gluten, maltodextrin, guar gum, carrageenan, citric acids	Mixing protein with hydrocolloids	Mishal *et al.* (2022)
Plant-based patty	Pea protein, chickpea flour, smoke extract, nutmeg, garlic powder, onion powder, black pepper extract, powdered allspice, sweet red pepper extract, and anthocyanin microcapsules	Mixing protein with hydrocolloids	Szpicer*et al.* (2022)
Plant protein-based sausages	80% pea protein isolate, 10% Pea protein concentrate and 10% of corn starch	Extrusion	Valtonen *et al.* (2023)
Vegetable-based frankfurter sausage	Smashed potatoes, cassava starch, soy protein concentrate, sodium tripolyphosphate, sodium erythorbate, spices, oat flour emulsion gel, flax seed emulsion gel	Mixing protein with hydrocolloids	Correa *et al.* (2023)
Vegetarian meatballs	Oyster mushrooms, tempeh flour, seasonings (fried shallots, salt, mushroom broth powder,	Mixing protein with	Yendro and Widyaningrum(2023)

	and pepper), egg white, water, tapioca flour, konjac flour, and oil	hydrocolloids	
Plant-based extrudates	Rapeseed protein concentrate and yellow pea isolate	Extrusion	Zahari *et al*. (2021)

Nutritional quality

Plant-based meat analogues (PBMA) are meticulously crafted to enhance the overall nutritional quality of the end product. In alignment with the stringent food labelling standards of the European Union and the United States, the pivotal nutritional parameters for assessing protein-based foods encompass total and saturated fat, total protein, total carbohydrate, dietary fibre, salt, and sugar content (Lappi *et al.,* 2022). When formulating PBMA, it is imperative to achieve a precise balance in the composition of fats, carbohydrates, salt, sugar, and flavouring agents to ensure both the quality and quantity of these constituents align with nutritional objectives.

Enhancing the health benefits of PBMA entails achieving an elevated ratio of unsaturated to saturated fats, coupled with a higher total dietary fibre content. The inclusion of dietary fibre not only contributes to an improved texture but also enhances the water-holding capacity of PBMA, resulting in a more appealing and nutritious product (Bakhsh *et al*., 2021). Typically, PBMA products exhibit a low-fat profile while delivering high protein content, replete with essential amino acids, rendering them favourable for human health (Kyriakopoulou *et al.,* 2021). Nonetheless, it is essential to acknowledge that the fate of these nutrients in the gastrointestinal tract remains a subject of ongoing investigation and warrants further exploration (Lee *et al.,* 2020).The meticulous consideration of these nutritional aspects in PBMA formulation not only aligns with the objectives of food labelling standards but also underscores the commitment to producing products that are both nutritionally sound and appealing to consumers. The ongoing research into the digestion and absorption of PBMA nutrients represents a critical area of inquiry, shedding light on their impact on human health and well-being.

Table 1 :Nutritional facts of some plant-based meat analogues and meat products

Product*	Energy (kcal)	Protein (g)	Fat (g)	Saturated fat (g)	Cholesterol (mg)	Total carbohydrates (g)	Dietary fibre (g)	Na (mg)	Fe (mg)
Plant-based meat analogues									
Beyond burger patties	203.5	17.69	12.38	4.42	0	6.19	1.769	345.13	3.539
Impossible burger patties	212.38	16.81	12.38	7.079	0	7.96	2.65	327.43	3.71
Quorn vegan	247	11.76	10.58	1.17	5.88	30.58	3.52	482.35	2.35

nuggets									
Gardein sausage	192.92	16.16	10.10	3.53	0	8.08	1.01	666.66	2.52
Morningstar chik'n nuggets	220.93	13.95	10.46	1.74	0	20.93	2.32	534.88	1.86
Tofurky Italian sausage	262.62	24.24	15.15	1.51	0	9.09	2.02	444.44	2.27
GoodDot vegetarian bytz	236.21	22.81	12.85	3.11	0	7.33	6.97	318	15.7
Blue Tribe plant-based chicken nuggets	229	7.06	11.51	1.45	<0.1	24.2	6.8	460	-
Tata plant-based chicken burger patty	186	17.4	8.4	1.1	0	10.2	-	676	-
Meat products									
Tyson chicken nuggets	298.70	15.58	19.48	4.54	45.45	16.88	0	532.46	0
Hormel chicken Vienna nuggets	100	5.45	8.18	2.72	50	0.9	0	363.63	0.65
McDonald's chicken nuggets	257.86	16.35	14.46	2.51	44.02	16.35	0	471.69	0.78
JBS beef patty	214.28	18.75	15.17	5.35	66.96	0	0	66.96	2.41

Source: Internet

*All products standardised to 100 g serving

Challenges

The development of plant-based meat analogues (PBMA) presents a set of distinctive challenges stemming from the inherent differences in structure and chemical composition between plant and muscle proteins. The intricate sensory profile of meat is notably challenging to replicate due to the inherent disparities in the type of proteins, amino acid compositions, peptide cross-links and flavour compounds between plants and meat. Moreover, the characteristic organization of muscle fibres, which imparts texture and the water-holding capacity of proteins, presents a significant hurdle in achieving a meat-like mouthfeel with PBMA. To address these disparities, various structuring processes, including thermomechanical extrusion, shear cell technology, water-binding agents, thickening agents and texture-improving agents, are employed in PBMA development.

Thermomechanical extrusion is a crucial process by which moist, expandable, starchy and proteinaceous food ingredients are plasticised and pushed through a die through a combination of temperature, pressure and mechanical shear (Maurya and Said, 2014). Additionally, the innovative shear cell technique, inspired by rheometry, allows for the application of intense shear in cone-in-cone or Couette geometries (Krintiras*et al*., 2014).

However, it is important to note that not all essential amino acids may be present in plant-based proteins. Achieving a balanced and complete amino acid profile necessitates the combination of different plant-based ingredients. The digestibility and bioavailability of individual amino acids within these proteins may be altered after blending and processing raw ingredients (Sa *et al.,* 2020).

Another significant challenge in PBMA development is the absence of the characteristic meat flavour (Graca *et al*., 2019). To compensate, flavouring ingredients, essential oils, spices and herbs are employed to simulate the meat flavour. However, the inclusion of ingredients like tannins, saponins, and isoflavones when using soy protein as the base for PBMA can result in bitter-astringent tastes. Achieving the distinct colour of meat in PBMA is also challenging, with leghemoglobin serving to provide the desired red or pink colour reminiscent of meat, particularly in cured meat products (Sha *et al.,* 2020).

Plant-based alternatives are not always inherently healthier options, as they may contain significantly higher levels of sodium compared to meat (Cole *et al.,* 2022).Moreover, the production of PBMA poses a financial challenge. Currently, PBMA products are relatively more expensive than conventional meat products and are priced at a substantial premium (Giacalone *et al.*, 2022). PBMA is four times as expensive as chicken, three times as expensive as pork, and twice as expensive as conventional beef, which hinders experimentation and regular consumption, especially among new consumers (Nezlek*et al.,* 2022). Despite the narrowing price gap, most consumers still consider cost a significant barrier (He *et al.,* 2020).

A significant issue in PBMA is the extended ingredient list, as the use of additives to address sensory challenges often results in long lists of unfamiliar elements, which can lead to a perception of PBMA as unhealthy and highly processed foods (Aschemann-Witzel *et al.,* 2021).

Furthermore, the digestibility of PBMA poses a challenge, with the blending of numerous ingredients potentially delaying or hindering the digestion process. Therefore, maintaining the formulation of PBMA minimal by eliminating ingredients that hinder digestion is crucial. Plant-based foods may also contain phytochemical factors such as trypsin inhibitors, tannins, phytates, and lectins that reduce the digestibility of plant proteins. Addressing these phytochemical anti-nutritional factors is essential to enhance the digestibility of plant proteins (Ishaq *et al.,* 2022). The presence of various flavouring substances, colourants and additives may contribute to variations in the digestion, assimilation and absorption of nutrients in PBMA.

Lastly, potential allergens, such as soybean protein (G2 Glycinin), which binds to IgE, can pose health risks to consumers, emphasizing the importance of allergen management in PBMA (Ahmad et al., 2022). Factors like gluten sensitivity, intolerance, and allergies may lead to coeliac disease in vulnerable age groups (Miller, 2018). Addressing these challenges is crucial in the development and consumer acceptance of PBMA as a viable and sustainable meat alternative.

Safety

The safety of plant-based meat analogues (PBMA) is a paramount concern, particularly given the intricate composition of these products. It is essential to address several factors that could affect both the digestion and overall safety of PBMA.Numerous ingredients added to PBMA formulations have been reported to potentially hinder or delay the digestion process. To mitigate these effects, it is advisable to simplify the formulation by removing ingredients that may impede digestion. These challenges often stem from anti-nutritional factors found in plant proteins. Key among these factors are tannins, phytates, lectins, and trypsin inhibitors. To enhance the digestibility of plant proteins, the deactivation of these anti-nutritional factors is of critical importance. Several studies have demonstrated that various processing methods, including conventional cooking, autoclaving, high-temperature extrusion, fermentation, microwave processing, freeze-drying and irradiation, can effectively improve the quality of plant proteins (Sa *et al.,* 2019). Improvements in the selection of protein sources and adherence to stringent safety standards during the processing of PBMA are essential for enhancing the overall safety of these products (He *et al.,* 2020).

One common issue in PBMA production is the lack of proper labelling. These products often contain a complex array of ingredients, typically numbering more than 20, including stabilizers, colourants and preservatives not commonly found in traditional meat products. Examples include methylcellulose, lecithin, and titanium dioxide. Furthermore, the elevated quantities of saturated fats and salt in PBMA can raise concerns about their adherence to health and nutritional standards. It is important to note that high-temperature processing methods, such as grilling, baking, roasting, and frying, may lead to the formation of toxicants and carcinogenic substances, including heterocyclic aromatic amines. These compounds are a concern and have been mainly identified in high-temperature treatments (Barzegar *et al.,* 2019; Jiang and Xiong, 2016). However, naturally occurring phenolic compounds have demonstrated inhibitory effects on the formation of these toxicants, potentially enhancing the safety of PBMA products (Lu *et al*., 2018; Xiong, 2017). Addressing these concerns, the Good Food Institute (2021) has proposed the use of non-extrusion techniques, including biological or chemical methods or their combinations, to denature and crosslink proteins gradually into fibrous structures without the need for high temperature or pressure. This approach holds promise for large-scale PBMA production while maintaining the nutritional quality and safety of the final product.

In some PBMA products, such as the Impossible Burger, soy leghemoglobin is used as a replacement for heme. This is achieved through the introduction of genetically engineered yeast, which incorporates the soy leghemoglobin gene into the yeast strain. Subsequently, the growth of yeast through fermentation and the isolation of soy leghemoglobin from it enhances flavour, aroma, and cooking properties (Jiang *et al.,* 2008).

However, it is important to acknowledge that some PBMA components, such as G2-glycinin, an IgE-binding protein found in soy, can pose allergenic risks (McClain *et al.,* 2014; Helm *et al*., 2000). These allergens may lead to various immunological responses, resulting in gastrointestinal, respiratory, skin-related, and cardiovascular issues. Notably, three categories of proteins, namely storage proteins, prolifins, and pathogenesis-related proteins, have been linked to allergenicity, highlighting the need for rigorous allergen management. Various studies have shown that treatments such as ultrasound, thermal processing, and high-pressure processing during PBMA formulation can significantly reduce the allergenicity of plant-based allergens (Cabanillas *et al.,* 2018). Furthermore, it's important to recognize that PBMA products formulated with wheat proteins may carry potential risks such as gluten intolerance and allergies (Miller, 2018). Addressing these safety concerns is crucial to ensure the well-being of consumers and the acceptance of PBMA as a safe and viable alternative to traditional meat products.

Consumer attitude

While the transition from traditional meat consumption to plant-based meat analogues (PBMA) offers potential health and environmental benefits (Hallstrom *et al*., 2015; Fresan and Sabate, 2019), a significant challenge persists: the majority of consumers are hesitant to fully replace meat with PBMA (Slade, 2018). PBMA products have predominantly targeted consumers who do not expect PBMA to mimic the exact texture and taste of meat, such as vegetarians and occasional meat consumers. However, many companies are now striving to create a new generation of PBMA that closely replicates the texture, flavour, and overall experience of traditional meat products, to win over non-vegetarian consumers. Convincing these consumers to embrace PBMA over traditional meat is a complex endeavour, as consumer behaviour is influenced by multiple factors. To gain widespread acceptance, food companies must prioritise enhancing the quality of PBMA to ensure it closely resembles traditional meat in terms of structure and sensory attributes. Additional determinants affecting consumer attitudes toward PBMA include education, personal income, and social media influence. In India, research showed that 5.5% of consumers were not at all likely to purchase plant-based meat, while 31.7% were somewhat or moderately likely, and a substantial 62.8% were very or extremely likely (Bryant *et al.,* 2019). A theoretical experiment conducted by Slade (2018), where both the taste and price of meat and PBMA were assumed to be equal, revealed that approximately 65% of consumers preferred conventional meat products, with only 21% favouring PBMA. Hoek *et al.* (2011) identified several significant factors hindering meat eaters from embracing meat substitutes, including the unfamiliarity of PBMA to most consumers and the taste and texture not matching traditional meat products. Subsequent research by Hoek et al. (2013) conducted a repeated consumption trial and observed an initial increased liking for meat analogues. However, after 20 exposures to three types of protein products, including conventional meat, meat analogues, and non-meat products, no particular product preference was discernible among consumers.

Strategies to Improve Consumer Acceptance

The consumer attitude toward PBMA is of paramount importance for its successful integration into the food market. Overcoming the obstacles to consumer acceptance necessitates a multifaceted approach. Addressing individual-related barriers requires sustained social education and guidance to increase consumer familiarity with PBMA and raise awareness of the personal health and environmental benefits (Vainio *et al*., 2018). Strategies employed in Western societies, such as incorporating designated meatless days into weekly meal plans, provide a model for gradually reducing global meat consumption.

To overcome product-related barriers, significant efforts should be directed at achieving a closer match to the texture and flavour of traditional meat (Hoek *et al.,* 2011). Consideration should extend beyond merely the resemblance of PBMA to traditional meat and also take into account meal types and consumer preferences (Elzerman *et al.,* 2015). Additionally, convenience-related aspects, including portion sizing, should be carefully considered during the development of new PBMA products (Schosler*et al.,* 2012).

The global shift toward reduced meat consumption is primarily influenced by consumer attitudes toward PBMA, and this shift continues to expand. A growing number of individuals are gradually adopting vegetarianism out of health consciousness. According to a survey conducted by Leahy et al. (2010), approximately 22% of the world's population is vegetarian, with nearly 34% of Indians identifying as vegetarian. Furthermore, the joint efforts of society, including public media, consumer awareness, and acceptance of PBMA, are on the rise, especially among urban populations. Bryant *et al.* (2019) surveyed in India and noted that non-meat eaters, higher-income groups, young demographics, and individuals with higher levels of education and knowledge about PBMA displayed a strong interest in consuming PBMA products. These strategies can contribute to enhancing consumer acceptance of PBMA and promoting sustainable dietary choices.

Conclusion

In the quest for more sustainable and healthier dietary choices, the emergence of plant-based meat analogues (PBMA) offers a promising avenue. These products are designed to replicate the sensory and nutritional characteristics of traditional meat while reducing the environmental impact associated with meat production. However, while the potential benefits are clear, the journey toward widespread consumer acceptance presents formidable challenges.

Consumer attitudes toward PBMA are influenced by a myriad of factors, from texture and taste to education, income, and social influence. The majority of consumers, especially non-vegetarians, remain hesitant to fully transition from conventional meat to PBMA. Their preference for traditional meat products, as revealed in theoretical experiments, underscores the obstacles faced by the PBMA industry. Factors such as unfamiliarity, taste disparities, and texture inconsistencies have contributed to the resistance.

To overcome these challenges and promote the acceptance of PBMA, a multipronged approach is required. First, PBMA companies must prioritize enhancing the quality of their products, with a particular focus on achieving a close resemblance to traditional meat. Consumer acceptance hinges on the ability of PBMA to provide not just a nutritious alternative but also a satisfying sensory experience.

Social education and awareness campaigns play a pivotal role in familiarizing consumers with PBMA and highlighting the potential health and environmental benefits. Lessons from Western societies, where designated meatless days have been incorporated into weekly meal plans to gradually reduce meat consumption, can serve as a valuable model.

Furthermore, product development efforts must consider consumer preferences beyond mere similarity to traditional meat, taking into account meal types and convenience-related aspects, including portion sizing. A holistic approach that accounts for various facets of consumer behaviour is essential to bridge the gap between consumer preferences and PBMA offerings.

The global shift toward reduced meat consumption is a significant development, driven by health consciousness and increasing awareness of environmental concerns. With nearly a quarter of the world's population identifying as vegetarian, the trend toward more sustainable dietary choices is unmistakable. Moreover, urban populations are witnessing a growing acceptance of PBMA, particularly among non-meat eaters, higher-income groups, the younger demographic, and individuals with higher education levels.

The journey to full consumer acceptance of PBMA is challenging, it is not insurmountable. The alignment of product quality, consumer education, and innovation in PBMA development will be pivotal in realizing the potential benefits of PBMA for both human health and the environment. By addressing the complexities of consumer attitudes and preferences, the PBMA industry can play a substantial role in the global shift toward more sustainable and nutritious dietary choices.

Declaration

Ethical Approval and Consent to Participate

Our institute does not require review-based studies to undergo ethical approval or any consent.

Consent for Publication

All the authors have given their consent for publication of the review article in your journal.

Data Availability

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

Abbreviation:

PBMA- Plant-based meat analogues
GHG- Greenhouse gases

USD- United States dollar
CAGR- Compound annual growth rate
TVP- Texturized vegetable protein
References :

Comment [L4]: It is recommended to use Reference System such as Mendeley

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