Innovations in Plant-Based Proteins: Nutritional Value and Consumer Acceptance

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Abstract- ***The burgeoning interest in plant-based proteins stems from a growing awareness of their health benefits, environmental sustainability, and potential to meet global food security needs. This paper provides a comprehensive exploration of the innovations, nutritional value, and consumer acceptance of plant-based proteins. Historically, legumes and pulses have been central to plant-based diets, valued for their rich nutrient profiles and environmental benefits. Technological advancements, such as high-pressure processing and fermentation, have significantly improved the quality and functionality of plant proteins, making them viable alternatives to animal proteins. Nutritionally, plant-based proteins offer several health benefits, including improved cardiovascular health, weight management, and reduced risks of chronic diseases. However, they often lack certain essential amino acids found in animal proteins. This gap can be bridged through strategic combinations of plant proteins and modern processing techniques. Fortification and supplementation further enhance the nutritional profile of plant-based diets, ensuring they meet all dietary requirements. Consumer acceptance of plant-based proteins is influenced by taste, texture, cost, and environmental concerns. Brands like MorninStar Farms, Impossible Foods and Beyond Meat have successfully navigated these challenges, creating products that closely mimic the sensory attributes of meat. The market for plant-based proteins is expanding rapidly, driven by technological innovations and increasing consumer demand for sustainable and ethical food options. Looking ahead, emerging trends such as synthetic biology, IoT automation, and 3D food printing are poised to revolutionize the plant-based protein industry. New protein sources, including underutilized legumes, aquatic plants, and fungi, offer promising alternatives that can enhance the diversity and sustainability of plant-based diets. This paper concludes that the ongoing advancements in food technology and consumer education will be crucial in sustaining the growth and acceptance of plant-based proteins, contributing significantly to global health and environmental sustainability.***

I. INTRODUCTION

Plant-based proteins have become increasingly significant in modern diets due to their potential health benefits and environmental sustainability. Historically, legumes and pulses have been primary sources of plant-based proteins, known for their rich nutritional profiles and affordability (Ball et al., 2021). The nutritional adequacy of plant proteins is well-documented, providing essential amino acids necessary for human health (Kumar et al., 2021). Innovations in extraction and processing technologies have improved the functional properties of plant proteins, making them suitable alternatives to animal proteins (Nikbakht Nasrabadi et al., 2021).

Despite their advantages, consumer acceptance of plant-based proteins varies, influenced by factors such as taste, texture, and psychological reactance (Bogueva et al., 2022). Health benefits, including lower cholesterol levels and reduced cardiovascular risks, further drive their adoption (Pawar, 2022). Additionally, the fermentation process enhances the quality and digestibility of plant proteins, making them more functional for diverse food applications (Alrosan et al., 2022). Thus, plant-based proteins represent a versatile and nutritionally valuable component of sustainable diets, contributing to improved public health and environmental outcomes.
Moreover, plant-based proteins have gained significant importance in the food industry due to their health benefits and sustainability. They are rich in bioactive compounds and essential nutrients, which contribute to reducing chronic diseases and improving overall human health (Luthje et al., 2015). Additionally, plant-based proteins are seen as sustainable alternatives, offering lower environmental

footprints compared to animal-based proteins (Singh et al., 2022).

The food industry has embraced plant-based proteins for their versatility and adaptability in creating new food products. For example, pseudocereals are highly valued for their nutritional profiles and potential as functional food ingredients (Poshadri et al., 2024). Technological advancements, such as plant polymer-based solid foams and nano-delivery systems, have enhanced the functional applications of plant-based proteins in food packaging and shelf-life improvement (Jarpa-Parra et al., 2021; Otchere et al., 2023).

Consumer demand for healthier and more sustainable food options has further driven the adoption of plant-based proteins. These proteins cater to various dietary preferences, including vegetarian and vegan diets, and address food allergies (Comunian et al., 2021). Consequently, the food industry continues to innovate and expand its use of plant-based proteins to meet evolving consumer needs and sustainability goals.

The purpose of this paper is to explore the innovations in plant-based proteins, their nutritional value, and the factors influencing consumer acceptance. The growing popularity of plant-based diets and the increasing demand for sustainable and healthy food alternatives underscore the importance of understanding these aspects comprehensively.

The scope of this paper encompasses the historical development of plant-based proteins, technological advancements in their production, and their nutritional benefits. It also examines the market trends, consumer perceptions, and challenges associated with plant-based proteins. By providing a detailed analysis of these areas, the paper aims to highlight the potential and limitations of plant-based proteins in the current food industry.

This paper begins with an introduction that highlights the background and significance of plant-based proteins. It then traces the historical context and evolution of plant-based proteins, followed by an exploration of innovations and technological advances in this area. A comprehensive analysis of the nutritional value of plant-based proteins is provided. The paper also examines consumer acceptance and market trends, featuring case studies of successful plant-based protein products. Finally, it concludes by discussing future directions and potential innovations in the field.

- Historical Context and Evolution

The use of plant-based proteins dates back to ancient civilizations, where they were integral to diets primarily due to their accessibility and nutritional value. Legumes, such as beans and lentils, were staple foods in many cultures and provided essential nutrients (Ball et al., 2021). Early agricultural societies relied heavily on these proteins to meet their dietary needs, as they were abundant and easily cultivated (Gao et al., 2018).

In Asia, soybeans were extensively used not only as a food source but also for their versatile applications in products like tofu and soy sauce, demonstrating early innovations in plant protein utilization (Yao et al., 2023). Similarly, ancient Mesoamerican civilizations cultivated and consumed amaranth and chia, recognizing their high protein content and health benefits (Norikane, 2015).

These early uses laid the foundation for the diverse applications of plant-based proteins seen today. They were not only crucial for nutrition but also for cultural and economic reasons, showcasing their importance in human history and development (Geurden et al., 2013). The traditional knowledge and practices surrounding these plant proteins continue to influence modern dietary patterns and food technology advancements.

The development of plant-based proteins has seen significant evolution over the decades, driven by advances in food science, technology, and changing consumer preferences. In the mid-20th century, plant-based proteins were primarily utilized in their raw forms, such as soybeans and lentils, valued for their nutritional content and affordability (Fu et al., 2023).

During the 1970s and 1980s, technological advancements enabled the production of more refined plant protein isolates and concentrates, which were incorporated into various food products to enhance protein content (Horn et al., 2003). This period also saw the introduction of textured vegetable proteins,

which mimicked the texture of meat and expanded the culinary applications of plant-based proteins (Daniel & Kassa, 2021).

In recent decades, the rise of health and environmental awareness has spurred a surge in demand for plant-based proteins. Innovative processing technologies, such as extrusion and fermentation, have been developed to improve the sensory attributes and nutritional profiles of plant-based meat analogues (Younis et al., 2022). The integration of biotechnology has further enhanced the functionality and bioavailability of plant proteins, making them viable substitutes for animal proteins (Sim et al., 2021). Therefore, the development of plant-based proteins reflects a dynamic interplay between technological innovation and evolving consumer demands, leading to their prominent role in the modern food industry.

The evolution of plant-based proteins has been marked by several key milestones. In the 1960s and 1970s, the development of soy protein isolates and textured vegetable proteins (TVP) was a significant breakthrough, providing a versatile ingredient for various food products (Horn et al., 2003). This period also saw the introduction of TVP as a meat extender, enhancing its utility in the food industry.

In the 1980s and 1990s, advancements in food processing technologies, such as extrusion and fermentation, improved the texture and flavor profiles of plant-based proteins, making them more appealing to consumers (Fu et al., 2023). The development of plant-based meat analogues, which mimic the sensory attributes of meat, further expanded the market for these products (Younis et al., 2022).

The 2000s and 2010s saw significant growth in the plant-based protein market, driven by increased consumer awareness of health and environmental issues. Innovations such as the introduction of the Impossible Burger and Beyond Meat products exemplified the potential of plant-based proteins to compete with traditional meat products (Bulah et al., 2023). These milestones underscore the dynamic and evolving landscape of plant-based protein innovations, reflecting the interplay of technological advancements and shifting consumer preferences.

- Innovations in Plant-Based Protein Sources

- Legumes and Pulses

Legumes and pulses have been central to human diets for millennia, providing essential nutrients and serving as a primary source of plant-based proteins. Key types include beans, lentils, chickpeas, peas, and various underutilized legumes like lupins and moth beans. These legumes are highly valued for their nutritional content and environmental benefits (Affrifah et al., 2023; Masih, 2024).

Beans, such as common beans and soybeans, are among the most widely consumed legumes. Soybeans, in particular, have been extensively studied and utilized in the production of various plant-based protein products, including tofu, soy milk, and textured vegetable protein (Fu et al., 2023). Lentils and chickpeas are also crucial, known for their versatility and high protein content. Innovations in processing techniques, such as extrusion and fermentation, have enhanced the functional properties of these legumes, making them suitable for a wider range of food products (Costa et al., 2022; Criste et al., 2023).

Underutilized legumes like lupins and moth beans are gaining attention for their unique nutritional profiles and potential health benefits. Australian sweet lupins, for example, are high in protein and fiber, with studies showing their positive effects on blood pressure, lipid profiles, and gut health (Kouris-Blazos & Belski, 2016). Moth beans, rich in protein and bioactive compounds, have been highlighted for their role in preventing obesity, diabetes, and cardiovascular diseases (Rani et al., 2023).

Moreover, legumes are nutritionally dense, offering a high protein content along with essential vitamins and minerals. They are particularly rich in lysine, an essential amino acid often limited in cereals, making them a complementary protein source in vegetarian and vegan diets (Thavarajah et al., 2023). Additionally, legumes are a significant source of dietary fiber, which aids in digestion and helps maintain healthy blood glucose levels.

The environmental benefits of legumes are also noteworthy. Their ability to fix nitrogen in the soil reduces the need for chemical fertilizers, promoting

sustainable agricultural practices (Masih, 2024). Furthermore, the low environmental footprint of legume cultivation, compared to animal-based protein sources, contributes to their growing popularity in the context of global food sustainability (Detzel et al., 2021).

- Grains and Seeds

Grains and seeds are fundamental sources of plant-based proteins, offering significant nutritional benefits and playing a crucial role in food security. Key types include quinoa, amaranth, millet, flaxseed, chia seeds, and hemp seeds. These grains and seeds are increasingly utilized in various innovative food products to meet the growing demand for plant-based diets (Daniel & Kassa, 2021; Fernández-Tomé et al., 2023).

Quinoa and amaranth are pseudocereals known for their high protein content and balanced amino acid profiles. These grains have been integrated into various food products, including protein bars, cereals, and flour blends, to enhance nutritional value (Fernández-Tomé et al., 2023). Millet, particularly pearl millet and finger millet, is another significant grain, valued for its rich content of dietary fiber, proteins, and essential micronutrients. Innovations in processing millet have led to the development of gluten-free products suitable for individuals with celiac disease or gluten intolerance (Kanojia et al., 2024).

Flaxseed and chia seeds are renowned for their high omega-3 fatty acid content, making them popular ingredients in health foods and supplements. These seeds are often used in smoothies, baked goods, and as toppings for salads and yogurt, providing both protein and beneficial fats (Joshi & Bisht, 2020). Hemp seeds are another versatile seed, rich in protein, healthy fats, and minerals. They are incorporated into plant-based milk, protein powders, and snack bars, enhancing the nutritional profile of these products (Nyhan et al., 2023).

Furthermore, grains and seeds are nutritionally dense, offering a plethora of health benefits. They are excellent sources of plant-based protein, providing essential amino acids required for various bodily functions. Quinoa and amaranth, for instance, contain all nine essential amino acids, making them complete protein sources (Fernández-Tomé et al., 2023). Millet is rich in dietary fiber, which aids in digestion and helps maintain healthy blood sugar levels (Kanojia et al., 2024).

Flaxseed and chia seeds are notable for their high omega-3 fatty acid content, which is essential for heart health and reducing inflammation. These seeds also provide dietary fiber and lignans, which have antioxidant properties and contribute to overall health (Joshi & Bisht, 2020). Hemp seeds are rich in protein, healthy fats, and minerals like magnesium and zinc, supporting various metabolic processes and improving overall nutritional intake (Nyhan et al., 2023).

- Nuts

Nuts and various other plant sources offer substantial nutritional benefits and have been the focus of numerous innovations in the realm of plant-based proteins. Key types include almonds, walnuts, cashews, and other lesser-known sources like seeds from fruits and vegetables. These sources are highly valued for their rich nutrient profiles and versatility in food applications (Joshi & Bisht, 2020; Estell et al., 2021; Costa et al., 2022; Nyhan et al., 2023).

Almonds are among the most popular nuts used in plant-based diets. They are incorporated into a variety of products, such as almond milk, almond butter, and protein bars. Innovations in processing have enhanced the texture and flavor of almond-based products, making them more appealing to consumers (Joshi & Bisht, 2020). Walnuts are another significant nut, known for their high omega-3 fatty acid content. They are often used in baking, cooking, and as a snack, providing a healthful alternative to other more processed foods (Nyhan et al., 2023).

Cashews are particularly versatile, used in products like cashew milk, cheese, and cream. The creamy texture of cashews makes them a popular ingredient in vegan and plant-based recipes, allowing for the creation of dairy-free alternatives that closely mimic the properties of traditional dairy products (Estell et al., 2021). Lesser-known sources, such as seeds from fruits and vegetables, are also gaining attention. For instance, pumpkin and sunflower seeds are being utilized for their high protein content and unique

flavors, incorporated into snacks, spreads, and even plant-based protein powders (Costa et al., 2022).

More so, nuts and seeds are nutritionally dense, providing a wealth of benefits. They are excellent sources of plant-based protein, healthy fats, vitamins, and minerals. Almonds, for example, are rich in vitamin E, magnesium, and fiber, contributing to heart health and improved digestive function (Joshi & Bisht, 2020). Walnuts provide significant amounts of omega-3 fatty acids, which are essential for brain health and reducing inflammation (Nyhan et al., 2023).

Cashews are notable for their high levels of monounsaturated fats, which can help reduce bad cholesterol levels and improve heart health. They also provide important minerals like copper and zinc, which are crucial for immune function and skin health (Estell et al., 2021). Pumpkin and sunflower seeds are rich in protein, iron, and magnesium, supporting muscle function and overall metabolic health (Costa et al., 2022). Hence, nuts and plant sources are essential for a plant-based diet due to their high nutritional value, versatility, and health benefits, promoting sustainable food practices.

- Technological Advances in Plant-Based Protein Production
- Extraction and Processing Technologies

Extraction and processing technologies are critical in the production of plant-based proteins, significantly impacting their quality, functionality, and nutritional value. These technologies have evolved considerably, with innovations aimed at enhancing efficiency, sustainability, and the sensory attributes of plant-based protein products (Chemat et al., 2017).

Traditional methods of protein extraction from plant sources often involve mechanical pressing and solvent extraction. Mechanical pressing is commonly used for oilseeds like soybeans, where the seeds are pressed to extract oil and protein-rich meal (Daniel & Kassa, 2021). Solvent extraction involves using solvents such as hexane to separate proteins from plant materials. While effective, solvent extraction poses environmental and health concerns due to the use of chemicals (Garcia-Vaquero, Rajauria and Tiwari, 2020).

To address these issues, aqueous extraction has gained popularity. This method uses water or water-based solutions to extract proteins, minimizing the use of harmful solvents. Aqueous extraction is particularly effective for legumes and pulses, yielding high-quality protein isolates with better nutritional profiles (Nyhan et al., 2023).

One of the significant advancements in plant-based protein processing is high-pressure processing (HPP). HPP involves subjecting protein-rich plant materials to high pressures, which enhances protein extraction efficiency and preserves the nutritional quality of the proteins. This method is particularly beneficial for delicate plant proteins that might be damaged by heat (Joshi & Bisht, 2020).

Another innovative technology is ultrasonic-assisted extraction (UAE). UAE uses high-frequency sound waves to disrupt plant cell walls, facilitating the release of proteins. This method is efficient and environmentally friendly, as it reduces the need for harsh chemicals and solvents (Estell et al., 2021). Enzyme-assisted extraction is also noteworthy, involving the use of specific enzymes to break down cell walls and enhance protein release. This method is highly specific and can be tailored to different plant sources to optimize protein yield and quality (Costa et al., 2022).

Extrusion technology has revolutionized the processing of plant-based proteins, especially in creating meat analogues. Extrusion involves forcing protein-rich dough through a shaped die under high pressure and temperature, transforming it into fibrous structures that mimic the texture of meat (Choton et al., 2020). This technology has been instrumental in producing high-quality, plant-based meat products with improved texture and mouthfeel (Nyhan et al., 2023).

- Fermentation and Biotechnology

Fermentation and biotechnology are at the forefront of enhancing the nutritional value of plant-based proteins, addressing both the sensory and functional limitations of these products. These technological advancements have led to the development of innovative food products that are not only nutritionally superior but also more palatable and appealing to

consumers (Sharma et al., 2020; Galimberti et al., 2021).

Fermentation is a time-honored method that has been adapted to improve the quality of plant-based proteins. Microbial fermentation, involving bacteria, yeast, and fungi, plays a crucial role in enhancing the nutritional profile of plant-based foods (Sharma et al., 2020). For instance, fermentation with microorganisms such as *Bacillus subtilis* and *Lactiplantibacillus plantarum* has been shown to improve the nutritional value and safety of plant-based meat analogs by reducing antinutritional factors and enhancing protein digestibility (Elhalis et al., 2023).

Solid-state fermentation (SSF) has been particularly effective in increasing the protein content and bioavailability of nutrients in plant-based substrates. For example, SSF using shiitake mushroom mycelium has been demonstrated to enhance the digestibility, flavor, and functionality of plant proteins, making them more suitable for human consumption (Clark et al., 2021). This method also significantly reduces phytate levels, which can inhibit the absorption of essential minerals (Li et al., 2023).

Biotechnology has opened new avenues for optimizing the nutritional properties of plant-based proteins. Genetic engineering and genome editing techniques, such as CRISPR-Cas9, are being used to modify the amino acid profiles of plants, enhancing their protein quality (Johnson et al., 2023). These modifications can lead to the production of plant proteins that are more comparable to animal proteins in terms of nutritional value.

Another biotechnological innovation is the use of enzyme-assisted extraction and processing. Enzymes can break down complex plant matrices, releasing proteins and other nutrients in a more bioavailable form. This method not only improves protein yield but also enhances the functional properties of the extracted proteins (Alrosan et al., 2022).

The integration of fermentation and biotechnological techniques has a profound impact on the nutritional value of plant-based proteins (Galimberti et al., 2021). Fermented plant proteins often exhibit improved digestibility and absorption rates, providing essential amino acids more efficiently than non-fermented counterparts (Boukid et al., 2023). Additionally, fermentation processes can enhance the content of vitamins and bioactive compounds, contributing to the overall health benefits of plant-based foods (Boukid et al., 2023).

- Novel Protein Sources: Algae, Fungi, and Lab-Grown Plant Proteins

The exploration of novel protein sources such as algae, fungi, and lab-grown plant proteins represents a significant advancement in addressing the global demand for sustainable and nutritionally rich food alternatives. These sources offer unique benefits and have been the focus of recent technological innovations aimed at improving their production and utilization in the food industry (van der Heijden et al., 2022).

Algae, particularly microalgae, are recognized for their high protein content and diverse biochemical composition. They can be cultivated in various environments, including freshwater, marine, and wastewater systems, making them a versatile and sustainable protein source (El Semary et al., 2023). Microalgae such as *Spirulina* and *Chlorella* are rich in essential amino acids, vitamins, and minerals. They have been used in supplements, functional foods, and as ingredients in plant-based meat products (Salter & Lopez-Viso, 2021). The cultivation of algae in mixotrophic conditions with supplements like sugarcane molasses can enhance growth and nutrient content, further increasing their viability as a food source (Semary et al., 2023).

Fungi, including mushrooms and mycelium, are another promising source of plant-based proteins. They can be grown on various substrates, including agricultural by-products, making them an environmentally friendly option. Fermentation with fungal species such as *Aspergillus* and *Trichoderma* can enhance the nutritional value of plant proteins by increasing their digestibility and reducing antinutritional factors (Jadhav & Mulla, 2024). Shiitake mushroom mycelium fermentation, for instance, has been shown to improve the flavor, nutritional value, and functionality of plant proteins, making them more suitable for human consumption (Clark et al., 2021).

Moreover, lab-grown or cultured plant proteins represent a cutting-edge approach to producing high-quality proteins in a controlled environment. This technology involves the use of bioreactors to cultivate plant cells or tissues, which can then be harvested for protein extraction (Ercili-Cura and Barth, 2021). Lab-grown proteins can be engineered to have specific nutritional profiles and functional properties, making them highly customizable for various food applications. This method also offers the potential for producing proteins with reduced environmental impact compared to traditional agricultural practices (Medeiros et al., 2024).

These novel protein sources not only provide high-quality protein but also offer additional health benefits (van der Heijden et al., 2022). Algae are rich in omega-3 fatty acids, antioxidants, and other bioactive compounds that contribute to overall health. Fungal proteins are easily digestible and can enhance the flavor and texture of plant-based foods. Lab-grown plant proteins can be tailored to meet specific dietary needs, ensuring a balanced intake of essential nutrients (van der Heijden et al., 2022). Hence, the integration of algae, fungi, and lab-grown plant proteins into the food industry is a significant step towards sustainable, nutritionally superior food systems.

- Nutritional Value of Plant-Based Proteins
- Amino Acid Profile and Bioavailability

The amino acid profile and bioavailability of plant-based proteins are critical factors in determining their nutritional adequacy compared to animal proteins. While plant-based proteins offer several health and environmental benefits, they often differ in essential amino acid composition and bioavailability from animal proteins (Hernández-Álvarez, Nosworthy and Mondor, 2022).

Plant-based proteins generally have a lower content of essential amino acids, such as lysine, methionine, and leucine, compared to animal proteins. For instance, grains are typically deficient in lysine, while legumes often lack methionine (Gorissen et al., 2018). This incomplete amino acid profile can be a limiting factor in achieving optimal protein nutrition solely from plant sources. However, combining different plant proteins, such as legumes and grains, can create a more balanced amino acid profile that closely matches that of animal proteins (Dimina et al., 2022).

Moreover, the bioavailability of plant-based proteins is often lower than that of animal proteins. This difference is due to the presence of antinutritional factors like phytates, tannins, and trypsin inhibitors in plant foods, which can impair protein digestion and amino acid absorption (Shankaran & Kumari, 2024). For example, phytates bind minerals and reduce their bioavailability, impacting the overall nutritional value of the proteins (Päivärinta et al., 2020).

Despite these challenges, various processing techniques have been developed to enhance the bioavailability of plant proteins. Fermentation, sprouting, and the application of phytase enzymes can significantly reduce antinutritional factors, thereby improving protein digestibility and amino acid absorption (Alrosan et al., 2022). Additionally, high-pressure processing and pulsed electric field treatments have shown promise in modifying plant proteins to enhance their functional and nutritional properties (Rathnakumar et al., 2023).

When comparing plant-based proteins to animal proteins, animal proteins generally provide a more complete amino acid profile and higher bioavailability. For example, whey protein, a high-quality animal protein, is rapidly digested and has a high content of branched-chain amino acids (BCAAs), which are crucial for muscle protein synthesis (Connolly et al., 2023). In contrast, plant proteins like soy and pea protein can support muscle synthesis but may require higher quantities or supplementation with specific amino acids to match the efficacy of animal proteins (Nichele et al., 2022).

- Health Benefits

Plant-based proteins offer a range of health benefits, particularly for cardiovascular health and weight management, making them valuable components of a healthy diet. Numerous studies have highlighted the cardiovascular benefits of plant-based proteins (Trautwein & McKay, 2020; Mullins & Arjmandi, 2021; Ferrari et al., 2022). Diets rich in plant proteins are associated with lower risks of heart disease due to their low levels of saturated fat and cholesterol, and high content of beneficial nutrients like fiber and

phytonutrients (Ferrari et al., 2022). For instance, plant-based diets can reduce blood lipid levels, lowering the risk of atherosclerosis and heart attacks. Specific components of plant-based diets, such as phytosterols and polyphenols, have been shown to improve cholesterol profiles and reduce oxidative stress, thereby enhancing cardiovascular health (Trautwein & McKay, 2020).

A randomized clinical trial demonstrated that replacing animal protein with plant protein sources led to improved blood lipoprotein profiles and increased fiber intake, both of which are beneficial for heart health (Päivärinta et al., 2020). Additionally, legumes and beans, which are rich in plant proteins, have been found to improve lipid metabolism and reduce inflammation, further supporting cardiovascular health (Mullins & Arjmandi, 2021).

Plant-based proteins are also effective in weight management. They are generally lower in calories and higher in dietary fiber compared to animal proteins, which promotes satiety and reduces overall calorie intake (Jurek, 2022). Diets high in plant proteins can help manage weight by increasing feelings of fullness and reducing the likelihood of overeating. This is particularly beneficial for individuals with obesity or those looking to maintain a healthy weight.

Studies have shown that plant-based diets can lead to significant weight loss and improvements in body composition. For example, a systematic review found that plant-based diets were effective in reducing body weight and improving metabolic health in individuals with overweight and type 2 diabetes (Tran et al., 2020). Moreover, the high fiber content of plant proteins aids in digestion and helps regulate blood sugar levels, which is crucial for weight management and preventing obesity-related diseases (Chen, 2024).
In addition to cardiovascular health and weight management, plant-based proteins offer various other health benefits. They are rich in antioxidants and anti-inflammatory compounds, which can help reduce the risk of chronic diseases such as cancer and diabetes. Plant-based diets also contribute to better gut health due to their high fiber content, promoting a healthy microbiome and improving overall digestive health (Behisht & N, 2022).

- Fortification and Supplementation

Plant-based proteins, while nutritionally beneficial, often require fortification and supplementation to address certain nutritional gaps compared to animal-based proteins. These strategies ensure that plant-based diets provide all essential nutrients necessary for optimal health (Olson et al., 2021). Fortification involves adding essential vitamins and minerals to plant-based foods to enhance their nutritional value. Plant-based beverages and yogurts are often fortified with calcium, vitamin D, vitamin B12, and iron to match or exceed the nutritional profiles of their dairy counterparts (Craig et al., 2021). For instance, fortified plant-based drinks can provide significant amounts of calcium and vitamin B12, which are typically lower in non-fortified plant-based products (Walther et al., 2022).

Fortification is particularly important for nutrients that are less bioavailable in plant-based diets. Iron, for example, is present in plant foods as non-heme iron, which is less readily absorbed than heme iron found in animal products. Fortifying plant-based foods with iron or consuming them alongside vitamin C-rich foods can enhance iron absorption (Sridhar et al., 2022).

Supplementation is another strategy to address nutritional gaps in plant-based diets. Essential nutrients like vitamin B12, which is naturally found in significant amounts only in animal products, need to be supplemented in a strictly plant-based diet to prevent deficiencies (Craig et al., 2021). Vitamin D and omega-3 fatty acids are also commonly supplemented, as their plant-based sources are limited and less bioavailable (Demir et al., 2023).

The protein quality of plant-based diets can be improved through strategic combinations and processing techniques. Combining different plant proteins, such as legumes and grains, can provide a more complete amino acid profile comparable to that of animal proteins (Fabris et al., 2024). Additionally, processes like fermentation and enzymatic treatment can enhance protein digestibility and reduce antinutritional factors, improving overall protein quality (Alrosan et al., 2022).

Innovative approaches like biofortification, where plants are bred or genetically modified to increase their nutrient content, offer promising solutions to micronutrient deficiencies in plant-based diets (Roy, 2022). This technique can significantly enhance the levels of essential vitamins and minerals in staple crops, improving the nutritional status of populations relying on plant-based diets (Roy, 2022).

- Comparative Analysis with Animal Proteins

Plant-based proteins and animal proteins differ significantly in their nutritional and functional properties, each offering unique benefits and challenges. Plant-based proteins, such as those derived from legumes, grains, and seeds, are generally lower in some essential amino acids compared to animal proteins. For instance, grains often lack lysine, while legumes may be deficient in methionine (Shankaran & Kumari, 2024). However, combining different plant proteins can create a complete amino acid profile that rivals animal proteins (Vatansever et al., 2020).

Plant-based proteins typically contain lower levels of saturated fats and cholesterol, contributing to better cardiovascular health. They are also rich in dietary fiber, vitamins, and phytonutrients, which are often lacking in animal proteins (Herrmann et al., 2024). However, the bioavailability of certain nutrients, such as iron and zinc, is generally lower in plant-based foods due to the presence of antinutritional factors like phytates (Sridhar et al., 2022).

From a functional perspective, plant-based proteins and animal proteins differ in their digestibility and protein quality. Animal proteins, such as whey and casein, are highly digestible and provide a complete amino acid profile, which is ideal for muscle protein synthesis (Fabris et al., 2024). Plant proteins, on the other hand, often require processing techniques like fermentation and enzymatic hydrolysis to enhance their digestibility and reduce antinutritional factors (Alrosan et al., 2022).

Plant-based meat substitutes (PBMS) have made significant strides in mimicking the texture and taste of animal meat. Products like soy-based burgers and pea protein sausages offer comparable protein content to conventional meat, albeit with different nutritional profiles. For example, PBMS tend to be higher in carbohydrates and fiber, but lower in saturated fats compared to meat (Gréa et al., 2023). Additionally, one of the primary advantages of plant-based proteins over animal proteins is their lower environmental footprint. Plant-based foods require less land, water, and energy to produce and generate fewer greenhouse gas emissions compared to animal-based foods (Herrmann et al., 2024). This environmental benefit is a significant factor driving the shift towards plant-based diets.

- Consumer Acceptance and Market Trends
- Consumer Perceptions and Attitudes

Consumer acceptance of plant-based proteins is shaped by a multitude of factors, including health benefits, environmental concerns, sensory attributes, and cultural influences. Health consciousness is a significant driver of consumer acceptance of plant-based proteins. Many consumers perceive plant-based diets as healthier alternatives due to their association with lower risks of chronic diseases, including cardiovascular diseases and certain cancers (Safdar et al., 2022). This perception is supported by scientific evidence highlighting the nutritional benefits of plant-based proteins, such as lower saturated fat content and higher dietary fiber (He et al., 2020).

Environmental sustainability is another critical factor influencing consumer attitudes. Growing awareness of the environmental impact of animal agriculture, including greenhouse gas emissions, deforestation, and water usage, has led many consumers to seek more sustainable dietary options (Chen, 2022). Plant-based proteins are perceived as more environmentally friendly, contributing to their increasing popularity (Bryant et al., 2019).

In addition, sensory qualities such as taste, texture, and appearance play a pivotal role in consumer acceptance. Despite the nutritional and environmental benefits, plant-based proteins must meet consumer expectations for flavor and mouthfeel to be widely accepted (Tireki et al., 2024). Research has shown that improving the sensory attributes of plant-based products, such as reducing off-flavors and enhancing texture, can significantly boost consumer acceptance (Mittermeier-Kleßinger et al., 2021).

Cultural factors also affect consumer attitudes towards plant-based proteins. In regions with strong meat-eating traditions, such as the USA and parts of Europe, acceptance of plant-based proteins may be lower due to cultural preferences for animal products (Bryant et al., 2019). Conversely, in countries like India and China, where vegetarian diets are more common, plant-based proteins are more readily accepted (Bryant et al., 2019).

Furthermore, market trends indicate a growing acceptance of plant-based proteins, driven by younger generations who are more health-conscious and environmentally aware. Millennials and Gen Z consumers are particularly influential in shaping food trends, showing a strong preference for sustainable and ethical food choices (Knaapila et al., 2022). Additionally, increased availability and variety of plant-based products in the market have made it easier for consumers to incorporate these proteins into their diets (Spendrup & Hovmalm, 2022).

- Market Growth and Trends: Statistics and Projections

The plant-based protein market has experienced significant growth in recent years, driven by increasing consumer demand for sustainable, healthy, and ethical food options (Ahmad, 2024; Thakur, 2020). This trend is expected to continue, with various projections indicating robust market expansion over the next decade.

The global market for plant-based proteins has been growing rapidly, with significant contributions from regions like North America, Europe, and Asia. In 2021, the plant-based protein market was valued at approximately $11.1 billion and is projected to reach $35.5 billion by 2032, growing at a compound annual growth rate (CAGR) of 12.5% (Ahmad, 2024). This growth is fueled by increasing consumer awareness of the health and environmental benefits of plant-based diets, alongside advancements in food technology that improve the taste and texture of plant-based products (Thakur, 2020).

Different regions exhibit varying levels of growth and consumer acceptance. In North America and Europe, the adoption of plant-based proteins is driven by health-conscious consumers and environmental concerns (Bryant & Sanctorum, 2021). For instance, in Belgium, acceptance of plant-based meat alternatives increased from 44% in 2019 to 51% in 2020, reflecting a positive trend in consumer attitudes towards these products (Bryant & Sanctorum, 2021).
In Asia, particularly in China and India, consumer acceptance of plant-based proteins is significantly higher due to cultural factors and the prevalence of vegetarian diets. Studies indicate that a substantial proportion of consumers in these countries are open to incorporating plant-based proteins into their diets (Bryant et al., 2019).

Moreover, several factors drive the growth of the plant-based protein market. Health benefits, such as reduced risk of chronic diseases and better weight management, are major motivators for consumers (Kirkpatrick & Marshall, 2022). Environmental concerns also play a crucial role, with consumers increasingly seeking sustainable food options that have a lower environmental footprint compared to animal-based products (Chen, 2022).

Looking ahead, the plant-based protein market is expected to continue its upward trajectory. Projections suggest that by 2030, more than half of consumers will adopt flexitarian diets, incorporating both plant-based and animal proteins (Ahmad, 2024). Technological advancements, such as improved protein extraction methods and innovative product formulations, will further enhance the market's growth potential (Li, 2021).

- Challenges and Barriers

Despite the growing popularity of plant-based proteins, several challenges and barriers persist, affecting consumer acceptance and market growth. Key issues include taste, texture, cost, and other sensory and non-sensory factors (McMillan, 2023; Tireki et al., 2024).

Taste is a critical factor influencing consumer acceptance of plant-based proteins. Many plant-based products struggle to replicate the rich, savory flavors of animal proteins, which can deter consumers. Off-flavors, often described as "beany" or "earthy," are common in plant-based products and can significantly reduce their appeal (Wang et al., 2022). Innovations such as fermentation and the use of flavor-masking

agents like cyclodextrins are being explored to improve the taste profiles of plant-based proteins (Sakai et al., 2022).

Texture is another major challenge for plant-based proteins. The fibrous and juicy texture of meat is difficult to replicate with plant ingredients. While technologies such as extrusion and high-moisture processing have improved the texture of plant-based meat analogues, achieving the exact mouthfeel of animal meat remains challenging (Appiani et al., 2023). Consumers often find plant-based products to be too dry or lacking in the succulence characteristic of meat, which affects their overall acceptance (Costa et al., 2022).

Moreover, cost is a significant barrier to the widespread adoption of plant-based proteins. Plant-based products are often more expensive than their animal-based counterparts, partly due to the complex processing methods and lower economies of scale (McMillan, 2023). This price disparity can limit access, particularly in developing economies where consumers may be more price-sensitive (Bakhsh et al., 2021). Several other factors also affect the acceptance of plant-based proteins. Consumer perceptions of plant-based products as highly processed can deter those seeking natural or minimally processed foods (Kraak, 2021). Additionally, dietary restrictions such as gluten intolerance and soy allergies can limit the appeal of some plant-based options (He et al., 2020).
In addition, environmental concerns and ethical considerations drive many consumers towards plant-based diets, but these motivators can be overshadowed by dissatisfaction with the sensory attributes of plant-based foods (Boukid, 2020). Addressing these challenges requires ongoing innovation in food technology to enhance taste, texture, and affordability, making plant-based proteins more competitive with traditional animal products.

- Case Studies of Successful Plant-Based Protein Products
- MorningStar Farms

MorningStar Farms, a pioneer in the plant-based protein industry, has successfully positioned itself as a prominent brand through strategic marketing, product development, and a commitment to environmental sustainability. Established in 1975 by Worthington Foods, MorningStar Farms was among the first to introduce modern meat analogs to the U.S. market. Despite early challenges, Kellogg's acquisition of Worthington Foods in 1999 and subsequent strategic initiatives have solidified MorningStar Farms' market presence (Shurtleff & Aoyagi, 2004; Byrd, 2014).

A key element of MorningStar Farms' success lies in its strong marketing strategies. Although the brand itself lacks a specific mission statement, Kellogg's overarching vision emphasizes creating a just world where people are fulfilled and nourished (Kelloggs, 2022). MorningStar Farms leverages this vision to highlight the environmental benefits of plant-based diets, appealing to environmentally conscious consumers. The brand's executive summary emphasizes its commitment to understanding and minimizing the environmental impacts of meatless meals, reinforcing its image as an eco-friendly choice (Morningstar Farms, 2021).

MorningStar Farms has effectively utilized various marketing growth strategies to expand its market share. The brand has invested significantly in increasing production capacity, with plans to expand its Zanesville, Ohio plant by 40,000-50,000 square feet, thereby boosting market penetration (Fusaro, 2020). Additionally, the introduction of the Incogmeato line, which includes realistic plant-based meat alternatives like Chick'n Tenders, reflects a strong product development strategy aimed at meeting consumer demand for products that closely resemble real meat (Forbes, 2021).

The brand's transition to fully vegan products by eliminating eggs from its offerings has further broadened its consumer base. This market development strategy appeals to a growing segment of consumers seeking entirely plant-based options (Forgrieve, 2019). MorningStar Farms' realistic products, such as the Chick'n Tenders, which closely mimic the taste and texture of real chicken, enhance consumer satisfaction and loyalty (Forbes, 2021).

Environmental awareness is a cornerstone of MorningStar Farms' brand identity. The company commissioned a life cycle assessment (LCA) to compare the environmental impacts of plant-based foods versus meat products. This study provided

valuable insights into the benefits of choosing plant-based options, reinforcing MorningStar Farms' commitment to sustainability (Morningstar Farms, 2021a). By making such information accessible on their website, the brand appeals to consumers motivated by environmental concerns.

MorningStar Farms also excels in exposure and accessibility. The brand's partnership with Sodexo has placed its products in over 3,000 hospitals and schools, significantly increasing consumer access (Webber, 2021). This widespread availability ensures that MorningStar Farms products are a convenient choice for a broad audience.

Hence, MorningStar Farms' success in the plant-based protein industry can be attributed to its effective marketing strategies, continuous product innovation, and strong commitment to environmental sustainability. By addressing consumer needs and leveraging its strengths, MorningStar Farms continues to thrive as a leader in the market.

- Impossible Foods

Impossible Foods has also emerged as a leader in the plant-based protein industry through significant technological innovations and a strong market presence. Founded in 2011, the company revolutionized plant-based meats by focusing on replicating the taste, texture, and cooking experience of traditional meat (Wilcox et al., 2023). A key innovation is the use of heme, an iron-containing molecule found in animal muscle, which they produce from genetically engineered yeast. This heme imparts a meat-like flavor and aroma to their products (Tziva et al., 2023).

The flagship product, the Impossible Burger, mimics the sensory attributes of beef, making it a popular choice among consumers seeking sustainable alternatives without compromising on taste. The burger's success is attributed to its ability to appeal to both vegetarians and meat-eaters alike, bridging the gap between traditional and plant-based diets (Wilcox et al., 2023; Detzel et al., 2021).

Impossible Foods' market impact is significant. By 2020, the company's products were available in over 17,000 restaurants and retailers globally, demonstrating rapid adoption and market penetration. The brand's strong emphasis on sustainability has resonated with environmentally conscious consumers, further driving its growth (Kirkpatrick & Marshall, 2022).

Furthermore, Impossible Foods has expanded its product line to include plant-based pork and sausage, catering to diverse consumer preferences and meal occasions. Their approach to innovation and sustainability has not only disrupted the traditional meat industry but also set a benchmark for other companies in the plant-based protein sector (Wilcox et al., 2023).

- Beyond Meat

Beyond Meat has significantly influenced the plant-based protein industry with its innovative approach to creating meat alternatives that closely mimic the taste and texture of animal meat. Founded in 2009, the company utilizes a variety of plant proteins, including pea, mung bean, and rice proteins, to develop products that provide a similar culinary experience to traditional meat (Wilcox et al., 2023).

A key innovation of Beyond Meat is its use of pea protein isolate, which forms the basis of its flagship product, the Beyond Burger. The company's proprietary process involves blending these proteins with fats, minerals, and flavorings to replicate the juiciness and chew of beef (Wilcox et al., 2023). The result is a product that not only appeals to vegetarians and vegans but also targets flexitarians and meat-eaters looking to reduce their meat consumption without sacrificing flavor and texture (Banach et al., 2022).

The market impact of Beyond Meat has been profound. The company's products are available in over 112,000 outlets worldwide, including major fast-food chains, grocery stores, and restaurants. This extensive market penetration reflects the growing consumer demand for plant-based protein options. Beyond Meat's success has also spurred investment in the plant-based sector, with the company raising over $240 million in its initial public offering in 2019 (Chaput & Paulsson, 2023).

Beyond Meat's commitment to sustainability is another critical aspect of its market impact. The company's products are designed to have a lower environmental footprint than traditional meat, requiring fewer resources and generating less greenhouse gas emissions (Wilcox et al., 2023). This sustainability message resonates strongly with environmentally conscious consumers, further driving the adoption of plant-based proteins (Kurt Klont et al., 2021). Hence, Beyond Meat's innovations in product development and its strong market presence have significantly advanced the plant-based protein industry, offering sustainable and nutritionally valuable alternatives to animal meat.

- Future Directions and Potential Innovations

The plant-based protein industry is witnessing several emerging trends and technological advancements aimed at enhancing product quality, sustainability, and consumer acceptance. These innovations are poised to shape the future of food production and consumption. Synthetic biology and genetic engineering are at the forefront of plant-based protein innovations. These technologies allow for the precise modification of plant genomes to enhance protein content and nutritional profiles. For example, CRISPR-Cas9 technology is used to improve the amino acid composition of plant proteins, making them more comparable to animal proteins (Hassoun et al., 2022). Additionally, genetic modifications can increase the yield and resilience of protein-rich crops, ensuring a stable and sustainable supply.

In addition, high-throughput phenomics and Internet of Things (IoT) automation are revolutionizing the agricultural practices related to plant-based protein production. These technologies enable precise monitoring and optimization of crop growth conditions, leading to higher efficiency and better quality of protein sources. IoT devices provide real-time data on soil health, moisture levels, and plant growth, facilitating data-driven decision-making and sustainable farming practices (Fabris et al., 2020).

Fermentation technology is also being extensively explored to enhance the nutritional and sensory qualities of plant-based proteins. Fermented plant proteins often exhibit improved digestibility, flavor, and texture. Advances in microbial fermentation techniques are enabling the production of novel fermented products that cater to diverse dietary preferences and enhance the overall appeal of plant-based foods (Hassoun et al., 2022).

Furthermore, 3D food printing provides an innovative technology that allows for the creation of customized plant-based protein products with specific nutritional profiles and aesthetic qualities. This technology can produce complex shapes and textures that mimic traditional meat products, improving the sensory experience for consumers. 3D printing also enables the incorporation of various plant proteins and other ingredients to create nutritionally balanced meals (Auyeskhan et al., 2024).

Exploring new sources of plant-based proteins is also crucial to meeting the growing global demand for sustainable and nutritionally rich food alternatives. Legumes such as lupins, mung beans, and pigeon peas are gaining attention for their high protein content and nutritional benefits. These legumes offer diverse amino acid profiles and are adaptable to various climatic conditions, making them viable options for enhancing global food security (Quintieri et al., 2023). Aquatic plants like duckweed and water lentils are also emerging as efficient protein sources. These plants grow rapidly and require minimal resources, making them environmentally sustainable. They are rich in essential amino acids and can be easily incorporated into various food products (Tan et al., 2024). More so, oilseeds such as pumpkin, sunflower, and hemp seeds are recognized for their high protein content and health benefits. These seeds are rich in essential fatty acids, vitamins, and minerals, making them excellent additions to plant-based diets. The protein extracted from oilseeds can be used in various food applications, including protein bars and dairy alternatives (Toutirais et al., 2024).

Fungi, particularly mycoprotein derived from fungi like *Fusarium venenatum*, also present a sustainable and high-protein alternative. Mycoprotein offers a meat-like texture and is rich in essential nutrients. It is already being used in various meat substitute products and holds potential for broader applications (Amara & El-Baky, 2023). Likewise, microalgae such as *Spirulina* and *Chlorella* are notable for their high protein content and rapid growth rates. These algae are

rich in essential amino acids, vitamins, and antioxidants. They can be cultivated in diverse environments and have a low environmental footprint, making them a sustainable protein source (Fabris et al., 2020).

In terms of market development, the plant-based protein market is poised for substantial growth, driven by increasing consumer demand for healthier, sustainable, and ethical food options. This trend is supported by favorable policy environments and advancements in food technology, which together create a robust market context for future developments (Aschemann-Witzel et al., 2020).

One key driver of market growth is the rising awareness of the health benefits and ecological advantages of plant-based diets. Consumers are increasingly seeking alternatives to traditional meat products due to concerns over health issues such as heart disease and the environmental impact of meat production (Thakur, 2020). This shift is expected to lead to significant market expansion for plant-based proteins, with products like pea protein, maize, and chickpeas gaining popularity (Thakur, 2020).

Technological innovations, particularly in plant protein structuring and fermentation processes, are set to improve the taste, texture, and nutritional profiles of plant-based products. These advancements will help meet consumer demands for high-quality meat analogues and dairy alternatives, making plant-based foods more appealing to a broader audience (Boukid, 2020).

The market is also expected to benefit from increased investment and innovation. Companies are focusing on developing new plant-based products and improving existing ones to cater to diverse dietary needs and preferences. This includes the introduction of novel protein sources and the enhancement of existing plant proteins to provide complete amino acid profiles and better digestibility (Li, 2021).

CONCLUSION

The exploration of plant-based proteins has evolved from a niche interest to a significant movement within the global food industry, driven by a combination of health, environmental, and ethical considerations. This paper has delved into the multifaceted aspects of plant-based proteins, from historical usage and technological innovations to nutritional benefits and consumer acceptance, providing a comprehensive overview of their current state and future potential.

Historically, legumes and pulses have been staple sources of plant-based proteins, providing essential nutrients and supporting agricultural sustainability. The advancements in extraction and processing technologies, such as high-pressure processing and ultrasonic-assisted extraction, have significantly enhanced the quality and applicability of plant proteins. Innovations in fermentation and biotechnology have further improved the nutritional value and sensory attributes of plant-based foods, making them more appealing to a broader consumer base.

The nutritional profile of plant-based proteins has been a focal point of research, highlighting both their strengths and areas for improvement. While plant-based proteins often lack one or more essential amino acids compared to animal proteins, strategic combinations and modern processing techniques can address these gaps. The health benefits of plant-based diets are well-documented, including improved cardiovascular health, weight management, and reduced risks of chronic diseases. Fortification and supplementation strategies are critical to ensuring that plant-based diets are nutritionally complete, providing essential vitamins and minerals that may be otherwise lacking.

Consumer perceptions and attitudes towards plant-based proteins are influenced by a variety of factors, including taste, texture, cost, and environmental concerns. The growing awareness of the health and ecological benefits of plant-based diets has driven market growth, with significant developments in product innovation and availability. Brands like MorningStar Farms, Impossible Foods and Beyond Meat have led the way with their successful market strategies, proving that plant-based proteins can compete with traditional animal products in terms of taste and texture. These case studies exemplify the potential for plant-based proteins to revolutionize the food industry. These companies have demonstrated

that it is possible to create products that not only meet but exceed consumer expectations, paving the way for future innovations.

Looking ahead, emerging trends and technologies such as synthetic biology, IoT automation, and 3D food printing are set to further transform the plant-based protein landscape. New sources of plant-based proteins, including underutilized legumes, aquatic plants, and fungi, offer promising alternatives that can enhance the diversity and sustainability of plant-based diets. The market is expected to continue its upward trajectory, with ongoing advancements in food technology and increasing consumer demand driving growth.

Hence, the journey of plant-based proteins from early uses to cutting-edge innovations reflects a broader shift towards sustainable and health-conscious food systems. The ongoing research and development in this field promise to address current challenges and unlock new opportunities, ensuring that plant-based proteins become an integral part of the global diet. As the industry continues to evolve, it is essential to focus on improving the nutritional quality, sensory attributes, and affordability of plant-based products to meet the diverse needs of consumers worldwide. By doing so, plant-based proteins can contribute significantly to global health, environmental sustainability, and food security, paving the way for a more sustainable future.

REFERENCES

[1] Affrifah, N.S., Uebersax, M.A. and Amin, S. (2023) "Nutritional significance, value-added applications, and consumer perceptions of food legumes: A review," *Legume Science*, 5(4). Available at: https://doi.org/10.1002/leg3.192.

[2] Ahmad, I. (2024) "The Nexus of Plant-Based Markets, Technological Advancements, Health and Safety Protocols, and Future Trajectories," *Journal of Culinary Science & Technology*, 22(3), pp. 373–385. Available at: https://doi.org/10.1080/15428052.2024.2345309.

[3] Alrosan, M., Tan, T.-C., Koh, W.Y., Easa, A.M., Gammoh, S. and Alu'datt, M.H. (2022) "Overview of fermentation process: structure-function relationship on protein quality and non-nutritive compounds of plant-based proteins and carbohydrates," *Critical Reviews in Food Science and Nutrition*, 63(25), pp. 7677–7691. Available at: https://doi.org/10.1080/10408398.2022.2049200.

[4] Amara, A.A. and El-Baky, N.A. (2023) "Fungi as a Source of Edible Proteins and Animal Feed," *Journal of Fungi*, 9(1), p. 73. Available at: https://doi.org/10.3390/jof9010073.

[5] Appiani, M., Cattaneo, C. and Laureati, M. (2023) "Sensory properties and consumer acceptance of plant-based meat, dairy, fish and eggs analogs: a systematic review," *Frontiers in Sustainable Food Systems*, 7. Available at: https://doi.org/10.3389/fsufs.2023.1268068.

[6] Aschemann-Witzel, J., Gantriis, R.F., Fraga, P. and Perez-Cueto, F.J.A. (2020) "Plant-based food and protein trend from a business perspective: markets, consumers, and the challenges and opportunities in the future," *Critical Reviews in Food Science and Nutrition*, 61(18), pp. 3119–3128. Available at: https://doi.org/10.1080/10408398.2020.1793730.

[7] Auyeskhan, U., Azhbagambetov, A., Sadykov, T., Dairabayeva, D., Talamona, D. and Chan, M.-Y. (2024) "Reducing meat consumption in Central Asia through 3D printing of plant-based protein—enhanced alternatives—a mini review," *Frontiers in Nutrition*, 10. Available at: https://doi.org/10.3389/fnut.2023.1308836.

[8] Bakhsh, A., Lee, S.-J., Lee, E.-Y., Hwang, Y.-H. and Joo, S.-T. (2021) "Traditional Plant-based Meat Alternatives, Current, and Future Perspective: A Review," *Journal of Agriculture and Life Science/Nong'eob Saengmyeong Gwahag Yeon'gu*, 55(1), pp. 1–11. Available at: https://doi.org/10.14397/jals.2021.55.1.1.

[9] Ball, J.J., Wyatt, R.P., Lambert, B.D., Smith, H.R., Reyes, T.M. and Sawyer, J.T. (2021) "Influence of Plant-Based Proteins on the Fresh and Cooked Characteristics of Ground Beef Patties," *Foods*, 10(9), p. 1971. Available at: https://doi.org/10.3390/foods10091971.

[10] Banach, J.L., Van Der Berg, J.P., Kleter, G., Van Bokhorst-Van De Veen, H., Bastiaan-Net,

S., Pouvreau, L. and Van Asselt, E.D. (2022) "Alternative proteins for meat and dairy replacers: Food safety and future trends," *Critical Reviews in Food Science and Nutrition*, 63(32), pp. 11063–11080. Available at: https://doi.org/10.1080/10408398.2022.2089625.

[11] Behisht, N. and R, N. (2022) "Impact of Plant-Based Diet in Prevention of Non-Communicable Diseases," 10(7), pp. 1015–1019. Available at: https://doi.org/10.22214/ijraset.2022.45428.

[12] Bogueva, D., Marinova, D. and Bryant, C. (2022) "Meat Me Halfway: Sydney Meat-Loving Men's Restaurant Experience with Alternative Plant-Based Proteins," *Sustainability*, 14(3), p. 1290. Available at: https://doi.org/10.3390/su14031290.

[13] Boukid, F. (2020) "Plant-based meat analogues: from niche to mainstream," *European Food Research & Technology*, 247(2), pp. 297–308. Available at: https://doi.org/10.1007/s00217-020-03630-9.

[14] Boukid, F., Hassoun, A., Zouari, A., Tülbek, M.Ç., Mefleh, M., Aït-Kaddour, A. and Castellari, M. (2023) "Fermentation for Designing Innovative Plant-Based Meat and Dairy Alternatives," *Foods*, 12(5), p. 1005. Available at: https://doi.org/10.3390/foods12051005.

[15] Bryant, C. and Sanctorum, H. (2021) "Alternative proteins, evolving attitudes: Comparing consumer attitudes to plant-based and cultured meat in Belgium in two consecutive years," *Appetite*, 161, p. 105161. Available at: https://doi.org/10.1016/j.appet.2021.105161.

[16] Bryant, C., Szejda, K., Parekh, N., Deshpande, V. and Tse, B. (2019) "A Survey of Consumer Perceptions of Plant-Based and Clean Meat in the USA, India, and China," *Frontiers in Sustainable Food Systems*, 3. Available at: https://doi.org/10.3389/fsufs.2019.00011.

[17] Bulah, B.M., Negro, S.O., Beumer, K. and Hekkert, M.P. (2023) "Institutional work as a key ingredient of food innovation success: The case of plant-based proteins," *Environmental Innovation and Societal Transitions*, 47, p. 100697. Available at: https://doi.org/10.1016/j.eist.2023.100697.

[18] Chaput, M. and Paulsson, A. (2023) "Bypassing the animal: Plant-based meat and the communicative constitution of a moral market," *Economy and Society/Economy and Society*, 52(2), pp. 274–297. Available at: https://doi.org/10.1080/03085147.2023.2168370.

[19] Chemat, F., Rombaut, N., Meullemiestre, A., Turk, M., Perino, S., Fabiano-Tixier, A.-S. and Abert-Vian, M. (2017) "Review of Green Food Processing techniques. Preservation, transformation, and extraction," *Innovative Food Science and Emerging Technologies/Innovative Food Science & Emerging Technologies*, 41, pp. 357–377. Available at: https://doi.org/10.1016/j.ifset.2017.04.016.

[20] Chen, H.-S. (2022) "Towards Environmentally Sustainable Diets: Consumer Attitudes and Purchase Intentions for Plant-Based Meat Alternatives in Taiwan," *Nutrients*, 14(18), p. 3853. Available at: https://doi.org/10.3390/nu14183853.

[21] Chen, Z. (2024) "The Role of Plant-Based Diet in Adolescent Obesity Rates and Its Potential as A Solution," *Medscien*, 1(7). Available at: https://doi.org/10.61173/vr9wrb37.

[22] Choton, S., Gupta, N., Bandral, J.D., Anjum, N. and Choudary, A. (2020) "Extrusion technology and its application in food processing: A review," *Pharma Innovation*, 9(2), pp. 162–168. Available at: https://doi.org/10.22271/tpi.2020.v9.i2d.4367.

[23] Clark, A., Soni, B.K., Sharkey, B., Acree, T., Lavin, E., Bailey, H.M., Stein, H.H., Han, A., Elie, M. and Nadal, M. (2021) "Shiitake mycelium fermentation improves digestibility, nutritional value, flavor and functionality of plant proteins," *bioRxiv (Cold Spring Harbor Laboratory)* [Preprint]. Available at: https://doi.org/10.1101/2021.10.07.463529.

[24] Comunian, T.A., Drusch, S. and Brodkorb, A. (2021) "Advances of plant-based structured food delivery systems on the in vitro digestibility of bioactive compounds," *Critical Reviews in Food Science and Nutrition*, 62(23), pp. 6485–6504. Available at:

https://doi.org/10.1080/10408398.2021.1902262.

[25] Connolly, G., Hudson, J.L., Bergia, R.E., Davis, E.M., Hartman, A.S., Zhu, W., Carroll, C.C. and Campbell, W.W. (2023) "Effects of Consuming Ounce-Equivalent Portions of Animal- vs. Plant-Based Protein Foods, as Defined by the Dietary Guidelines for Americans on Essential Amino Acids Bioavailability in Young and Older Adults: Two Cross-Over Randomized Controlled Trials," *Nutrients*, 15(13), p. 2870. Available at: https://doi.org/10.3390/nu15132870.

[26] Costa, I.M., Barbosa, C.D. and Da Silva, N.H.A. (2022) "Plant-based products: potential, production technology and challenges," ˜ *the œJournal of Engineering and Exact Sciences*, 8(7), pp. 14788–01e. Available at: https://doi.org/10.18540/jcecvl8iss7pp14788-01e.

[27] Craig, W.J. and Brothers, C.J. (2021) "Nutritional Content and Health Profile of Non-Dairy Plant-Based Yogurt Alternatives," *Nutrients*, 13(11), p. 4069. Available at: https://doi.org/10.3390/nu13114069.

[28] Criste, A.D., Urcan, A.C., Coroian, C.O., Copolovici, L., Copolovici, D.M., Burtescu, R.F. and Oláh, N.K. (2023) "Plant-Based Beverages from Germinated and Ungerminated Seeds, as a Source of Probiotics, and Bioactive Compounds with Health Benefits—Part 1: Legumes," *Agriculture*, 13(6), p. 1185. Available at: https://doi.org/10.3390/agriculture13061185.

[29] Daniel, I.O. and Kassa, M.T. (2021) "Advances in Food Development with Plant-Based Proteins from Seed Sources," in *IntechOpen eBooks*. Available at: https://doi.org/10.5772/intechopen.96273.

[30] Demir, H., Aydemir, L.Y., Özel, M.Ş., Koca, E. and Aslanoğlu, M.Ş. (2023) "Application of plant-based proteins for fortification of oat yogurt storage stability and bioactivity," *Journal of Food Science*, 88(10), pp. 4079–4096. Available at: https://doi.org/10.1111/1750-3841.16729.

[31] Detzel, A., Krüger, M., Busch, M., Blanco-Gutiérrez, I., Varela, C., Manners, R., Bez, J. and Zannini, E. (2021) "Life cycle assessment of animal-based foods and plant-based protein-rich alternatives: an environmental perspective," *Journal of the Science of Food and Agriculture/Journal of the Science of Food and Agriculture*, 102(12), pp. 5098–5110. Available at: https://doi.org/10.1002/jsfa.11417.

[32] Dimina, L., Rémond, D., Huneau, J.-F. and Mariotti, F. (2022) "Combining Plant Proteins to Achieve Amino Acid Profiles Adapted to Various Nutritional Objectives—An Exploratory Analysis Using Linear Programming," *Frontiers in Nutrition*, 8. Available at: https://doi.org/10.3389/fnut.2021.809685.

[33] E, Kurt, E, Klont and O, E. (2021) "White Paper - Plant Based Meat - Texturizing Plant Proteins," *Austin Food Sciences*, 6(1). Available at: https://doi.org/10.26420/austinfoodsci.2021.1043.

[34] Elhalis, H., See, X.Y., Osen, R., Chin, X.H. and Chow, Y. (2023) "Significance of Fermentation in Plant-Based Meat Analogs: A Critical Review of Nutrition, and Safety-Related Aspects," *Foods*, 12(17), p. 3222. Available at: https://doi.org/10.3390/foods12173222.

[35] Ercili-Cura, D. and Barth, D. (2021) *Cellular Agriculture*. American Chemical Society. Available at: http://books.google.ie/books?id=R8YkEAAAQBAJ&printsec=frontcover&dq=Ercili-Cura,+D.+and+Barth,+D.,+2021.+Cellular+Agriculture:+Lab+Grown+Foods+(Vol.+8).+American+Chemical+Society.&hl=&cd=1&source=gbs_api.

[36] Estell, M., Hughes, J. and Grafenauer, S. (2021) "Plant Protein and Plant-Based Meat Alternatives: Consumer and Nutrition Professional Attitudes and Perceptions," *Sustainability*, 13(3), p. 1478. Available at: https://doi.org/10.3390/su13031478.

[37] *Executive Summary* (2021) *MorningStar Farms*. Available at: https://www.morningstarfarms.com/en_US/executive-summary.html (Accessed: July 21, 2024).

[38] Fabris, L.V., Santos, L.M.D. and Stefani, G.P. (2024) "Comparative analysis of the protein content and nutritional label of whey protein, plant-based, and animal proteins supplements," *Revista Contexto & Saúde*, 24(48), p. e14497. Available at: https://doi.org/10.21527/2176-7114.2024.48.14497.

[39] Fabris, M., Abbriano, R.M., Pernice, M., Sutherland, D.L., Commault, A.S., Hall, C.C., Labeeuw, L., McCauley, J.I., Kuzhiuparambil, U., Ray, P., Kahlke, T. and Ralph, P.J. (2020) "Emerging Technologies in Algal Biotechnology: Toward the Establishment of a Sustainable, Algae-Based Bioeconomy," *Frontiers in Plant Science*, 11. Available at: https://doi.org/10.3389/fpls.2020.00279.

[40] Fernández-Tomé, S., Ashaolu, T.J. and Hernández-Ledesma, B. (2023) "Exploration of the Nutritional and Functional Properties of Underutilized Grains as an Alternative Source for the Research of Food-Derived Bioactive Peptides," *Nutrients*, 15(2), p. 351. Available at: https://doi.org/10.3390/nu15020351.

[41] Ferrari, L., Panaite, S.-A., Bertazzo, A. and Visioli, F. (2022) "Animal- and Plant-Based Protein Sources: A Scoping Review of Human Health Outcomes and Environmental Impact," *Nutrients*, 14(23), p. 5115. Available at: https://doi.org/10.3390/nu14235115.

[42] Forgrieve, J. (2021) "MorningStar Farms Grows Its Plant-Based Incogmeato Line With New Chik'n Tenders," *Forbes*, 20 April. Available at: https://www.forbes.com/sites/janetforgrieve/2021/04/20/morningstar-farms-grows-its-plant-based-incogmeato-line-with-new-chikn-tenders/.

[43] Fu, Q., Zhao, J., Rong, S., Han, Y., Liu, F., Chu, Q., Wang, S. and Chen, S. (2023) "Research Advances in Plant Protein-Based Products: Protein Sources, Processing Technology, and Food Applications," *Journal of Agricultural and Food Chemistry*, 71(42), pp. 15429–15444. Available at: https://doi.org/10.1021/acs.jafc.3c02224.

[44] Galimberti, A., Bruno, A., Agostinetto, G., Casiraghi, M., Guzzetti, L. and Labra, M. (2021) "Fermented food products in the era of globalization: tradition meets biotechnology innovations," *Current Opinion in Biotechnology*, 70, pp. 36–41. Available at: https://doi.org/10.1016/j.copbio.2020.10.006.

[45] Gao, Y., Wang, W., Zhang, T., Gong, Z., Zhao, H. and Han, G.-Z. (2018) "Out of Water: The Origin and Early Diversification of Plant R-Genes," *Plant Physiology*, 177(1), pp. 82–89. Available at: https://doi.org/10.1104/pp.18.00185.

[46] Garcia-Vaquero, M., Rajauria, G. and Tiwari, B. (2020) "Conventional extraction techniques: Solvent extraction," in *Elsevier eBooks*, pp. 171–189. Available at: https://doi.org/10.1016/b978-0-12-817943-7.00006-8.

[47] Geurden, I., Borchert, P., Balasubramanian, M., Schrama, J.W., Dupont-Nivet, M., Quillet, E., Kaushik, S., Panserat, S. and Médale, F. (2013) "The Positive Impact of the Early-Feeding of a Plant-Based Diet on Its Future Acceptance and Utilisation in Rainbow Trout," *PloS One*, 8(12), p. e83162. Available at: https://doi.org/10.1371/journal.pone.0083162.

[48] Gorissen, S.H.M., Crombag, J.J.R., Senden, J.M.G., Waterval, W. a. H., Bierau, J., Verdijk, L.B. and Van Loon, L.J.C. (2018) "Protein content and amino acid composition of commercially available plant-based protein isolates," *Amino Acids*, 50(12), pp. 1685–1695. Available at: https://doi.org/10.1007/s00726-018-2640-5.

[49] Gréa, C., Dittmann, A., Wolff, D., Werner, R., Turban, C., Roser, S., Hoffmann, I. and Bonsmann, S.S.G. (2023) "Comparison of the Declared Nutrient Content of Plant-Based Meat Substitutes and Corresponding Meat Products and Sausages in Germany," *Nutrients*, 15(18), p. 3864. Available at: https://doi.org/10.3390/nu15183864.

[50] Hassoun, A., Cropotova, J., Trif, M., Rusu, A.V., Bobiş, O., Nayik, G.A., Jagdale, Y.D., Saeed, F., Afzaal, M., Mostashari, P., Khaneghah, A.M. and Regenstein, J.M. (2022) "Consumer acceptance of new food trends resulting from the fourth industrial revolution technologies: A narrative review of literature and future perspectives," *Frontiers in Nutrition*, 9. Available at: https://doi.org/10.3389/fnut.2022.972154.

[51] He, J., Evans, N.M., Liu, H. and Shao, S. (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), pp. 2639–2656. Available at: https://doi.org/10.1111/1541-4337.12610.

[52] Hernández-Álvarez, A.J., Nosworthy, M.G. and Mondor, M. (2022) "Amino Acid Profile and Bioavailability of Plant-Based Protein-Rich Products," in *Springer eBooks*, pp. 343–379. Available at: https://doi.org/10.1007/978-3-030-91206-2_12.

[53] Herrmann, M., Mehner, E., Egger, L., Portmann, R., Hammer, L. and Nemecek, T. (2024) "A comparative nutritional life cycle assessment of processed and unprocessed soy-based meat and milk alternatives including protein quality adjustment," *Frontiers in Sustainable Food Systems*, 8. Available at: https://doi.org/10.3389/fsufs.2024.1413802.

[54] Horn, M.E., Pappu, K.M., Bailey, M.R., Clough, R.C., Barker, M., Jilka, J.M., Howard, J.A. and Streatfield, S.J. (2003) "Advantageous Features of Plant-based Systems for the Development of HIV Vaccines," *Journal of Drug Targeting*, 11(8–10), pp. 539–545. Available at: https://doi.org/10.1080/10611860410001669992.

[55] Jarpa-Parra, M. and Chen, L. (2021) "Applications of Plant Polymer-Based Solid Foams: Current Trends in the Food Industry," *Applied Sciences*, 11(20), p. 9605. Available at: https://doi.org/10.3390/app11209605.

[56] Johnson, N., Boatwright, J.L., Bridges, W., Thavarajah, P., Kumar, S. and Thavarajah, D. (2023) "Targeted improvement of plant-based protein: Genome-wide association mapping of a lentil (Lens culinaris Medik.) diversity panel," *Plants, People, Planet*, 6(3), pp. 640–655. Available at: https://doi.org/10.1002/ppp3.10470.

[57] Joshi, H. and Bisht, B. (2020) "A REVIEW: NUTRITIONAL BENEFITS OF PLANT-BASED SEED-NUT BUTTER," *International Journal of Engineering Applied Science and Technology*, 5(1), pp. 471–473. Available at: https://doi.org/10.33564/ijeast.2020.v05i01.082.

[58] Jurek, J.M. (2022) "Implications of Plant Foods in Weight Management: Focus on Metabolic Health," *Journal of Biomedical Research & Environmental Sciences*, 3(12), pp. 1440–1450. Available at: https://doi.org/10.37871/jbres1618.

[59] Kanojia, S., Gomadhi, G., Kamalasundari, S., Malathi, G., Krishnaveni, S.A., Ramasamy, M., Dhanalakshmi, K., Chitra, K. and Debnath, A. (2024) "Exploring Millet Grains: Nutritional Benefits, Processing Advancements, and Future Directions for Food Security and Health Improvement," *European Journal of Nutrition & Food Safety*, 16(5), pp. 101–108. Available at: https://doi.org/10.9734/ejnfs/2024/v16i51426.

[60] Kirkpatrick, E. and Marshall, M. (2022) "Spotlight on sustainability: How growing consumer preferences are changing the plant-based protein industry," *Proceedings of 2022 AOCS Annual Meeting &Amp; Expo* [Preprint]. Available at: https://doi.org/10.21748/gggk2278.

[61] Knaapila, A., Michel, F., Jouppila, K., Sontag-Strohm, T. and Piironen, V. (2022) "Millennials' Consumption of and Attitudes toward Meat and Plant-Based Meat Alternatives by Consumer Segment in Finland," *Foods*, 11(3), p. 456. Available at: https://doi.org/10.3390/foods11030456.

[62] Kouris-Blazos, A. and Belski, R. (2016) "Health benefits of legumes and pulses with a focus on Australian sweet lupins.," *PubMed*, 25(1), pp. 1–17. Available at: https://doi.org/10.6133/apjcn.2016.25.1.23.

[63] Kraak, V.I. (2022) "Perspective: Unpacking the Wicked Challenges for Alternative Proteins in the United States: Can Highly Processed Plant-Based and Cell-Cultured Food and Beverage Products Support Healthy and Sustainable Diets and Food Systems?," *Advances in Nutrition*, 13(1), pp. 38–47. Available at: https://doi.org/10.1093/advances/nmab113.

[64] Kumar, M., Tomar, M., Punia, S., Dhakane-Lad, J., Dhumal, S., Changan, S., Senapathy, M., Berwal, M.K., Sampathrajan, V., Sayed,

A.A.S., Chandran, D., Pandiselvam, R., Rais, N., Mahato, D.K., Udikeri, S.S., Satankar, V., Anitha, T., Reetu, N., Radha, N., Singh, S., Amarowicz, R. and Kennedy, J.F. (2022) "Plant-based proteins and their multifaceted industrial applications," *Lebensmittel-Wissenschaft + Technologie/Food Science & Technology*, 154, p. 112620. Available at: https://doi.org/10.1016/j.lwt.2021.112620.

[65] Li, C., Li, S., Zhu, Y., Chen, S., Wang, X., Deng, X., Liu, G., Beckers, Y. and Cai, H. (2023) "Improving the Nutritional Value of Plant Protein Sources as Poultry Feed through Solid-State Fermentation with a Special Focus on Peanut Meal—Advances and Perspectives," *Fermentation*, 9(4), p. 364. Available at: https://doi.org/10.3390/fermentation9040364.

[66] Li, Y. (2021) "Feeding the Future: Plant-Based Meat for Global Food Security and Environmental Sustainability," *Cereal Foods World*, 65(4). Available at: https://doi.org/10.1094/cfw-65-4-0042.

[67] Lüthje, S., Deswal, R. and Agrawal, G.K. (2015) "Plant-based Foods: Seed, Nutrition and Human Health," *Proteomics*, 15(10), p. 1638. Available at: https://doi.org/10.1002/pmic.201570083.

[68] McMillan, C. (2023) "The rivalry trap – plant-based foods as transformers and destroyers," *Journal of Business Strategy/˜ the œJournal of Business Strategy*, 45(1), pp. 48–57. Available at: https://doi.org/10.1108/jbs-06-2022-0102.

[69] Medeiros, F., Aleman, R.S., Gabríny, L., You, S.W., Hoskin, R.T. and Moncada, M. (2024) "Current Status and Economic Prospects of Alternative Protein Sources for the Food Industry," *Applied Sciences*, 14(9), p. 3733. Available at: https://doi.org/10.3390/app14093733.

[70] Mittermeier-Kleßinger, V.K., Hofmann, T. and Dawid, C. (2021) "Mitigating Off-Flavors of Plant-Based Proteins," *Journal of Agricultural and Food Chemistry*, 69(32), pp. 9202–9207. Available at: https://doi.org/10.1021/acs.jafc.1c03398.

[71] Mullins, A.P. and Arjmandi, B.H. (2021) "Health Benefits of Plant-Based Nutrition: Focus on Beans in Cardiometabolic Diseases," *Nutrients*, 13(2), p. 519. Available at: https://doi.org/10.3390/nu13020519.

[72] Nasrabadi, M.N., Doost, A.S. and Mezzenga, R. (2021) "Modification approaches of plant-based proteins to improve their techno-functionality and use in food products," *Food Hydrocolloids*, 118, p. 106789. Available at: https://doi.org/10.1016/j.foodhyd.2021.106789.

[73] Nichele, S., Phillips, S.M. and Boaventura, B.C.B. (2022) "Plant-based food patterns to stimulate muscle protein synthesis and support muscle mass in humans: a narrative review," *Applied Physiology, Nutrition and Metabolism/Applied Physiology, Nutrition, and Metabolism*, 47(7), pp. 700–710. Available at: https://doi.org/10.1139/apnm-2021-0806.

[74] Norikane, J.H. (2015) "The Potential of LEDs in Plant-based Bio-pharmaceutical Production," *HortScience*, 50(9), pp. 1289–1292. Available at: https://doi.org/10.21273/hortsci.50.9.1289.

[75] Nyhan, L., Sahin, A.W., Schmitz, H.H., Siegel, J.B. and Arendt, E.K. (2023) "Brewers' Spent Grain: An Unprecedented Opportunity to Develop Sustainable Plant-Based Nutrition Ingredients Addressing Global Malnutrition Challenges," *Journal of Agricultural and Food Chemistry*, 71(28), pp. 10543–10564. Available at: https://doi.org/10.1021/acs.jafc.3c02489.

[76] Olson, R., Gavin-Smith, B., Ferraboschi, C. and Kraemer, K. (2021) "Food Fortification: The Advantages, Disadvantages and Lessons from Sight and Life Programs," *Nutrients*, 13(4), p. 1118. Available at: https://doi.org/10.3390/nu13041118.

[77] Otchere, E., McKay, B.M., English, M.M. and Aryee, A.N.A. (2023) "Current trends in nano-delivery systems for functional foods: a systematic review," *PeerJ*, 11, p. e14980. Available at: https://doi.org/10.7717/peerj.14980.

[78] Päivärinta, E., Itkonen, S., Pellinen, T., Lehtovirta, M., Erkkola, M. and Pajari, A.-M. (2020) "Replacing Animal-Based Proteins with Plant-Based Proteins Changes the Composition of a Whole Nordic Diet—A Randomised Clinical Trial in Healthy Finnish Adults,"

Nutrients, 12(4), p. 943. Available at: https://doi.org/10.3390/nu12040943.

[79] Pawar, A. (2022) "A Review on Plant-based Proteins," *Bombay Technologist/Bombay Technologist* [Preprint]. Available at: https://doi.org/10.36664/bt/2022/v69i1/172536.

[80] Poshadri, A., Deshpande, H. and Kshirsagar, R.B. (2024) "Pseudocereals: Development of functional foods, their properties, challenges, and opportunities in food processing industry," *International Food Research Journal*, 31(2), pp. 266–275. Available at: https://doi.org/10.47836/ifrj.31.2.01.

[81] Quintieri, L., Nitride, C., De Angelis, E., Lamonaca, A., Pilolli, R., Russo, F. and Monaci, L. (2023) "Alternative Protein Sources and Novel Foods: Benefits, Food Applications and Safety Issues," *Nutrients*, 15(6), p. 1509. Available at: https://doi.org/10.3390/nu15061509.

[82] Rani, J., Dhull, S.B., Kinabo, J., Kidwai, Mohd.K. and Sangwan, A. (2023) "A narrative review on nutritional and health benefits of underutilized summer crop to address agriculture challenges: Moth bean (Vigna aconitifolia L.)," *Legume Science*, 5(4). Available at: https://doi.org/10.1002/leg3.204.

[83] Rathnakumar, K., Balakrishnan, G., Ramesh, B., Sujayasree, O.J., Pasupuleti, S.K. and Pandiselvam, R. (2023) "Impact of emerging food processing technologies on structural and functional modification of proteins in plant-based meat alternatives: An updated review," *Journal of Texture Studies*, 54(4), pp. 599–612. Available at: https://doi.org/10.1111/jtxs.12747.

[84] Roy, B. (2022) "BIO-FORTIFICATION; FUTURE CHALLENGES TOWARD NUTRITIONAL SECURITY: MINI REVIEW," *Plant Archives/Plant Archives*, pp. 231–237. Available at: https://doi.org/10.51470/plantarchives.2022.v22.no1.036.

[85] Safdar, B., Zhou, H., Li, H., Cao, J., Zhang, T., Ying, Z. and Liu, X. (2022) "Prospects for Plant-Based Meat: Current Standing, Consumer Perceptions, and Shifting Trends," *Foods*, 11(23), p. 3770. Available at: https://doi.org/10.3390/foods11233770.

[86] Sakai, K., Sato, Y., Okada, M. and Yamaguchi, S. (2022) "Cyclodextrins produced by cyclodextrin glucanotransferase mask beany off-flavors in plant-based meat analogs," *PloS One*, 17(6), p. e0269278. Available at: https://doi.org/10.1371/journal.pone.0269278.

[87] Salter, A.M. and Lopez-Viso, C. (2021) "Role of novel protein sources in sustainably meeting future global requirements," *Proceedings of the Nutrition Society*, 80(2), pp. 186–194. Available at: https://doi.org/10.1017/s0029665121000513.

[88] Semary, N.E., El-Sattar, A.M.A., Ahmed, E.Z. and Aldayel, M. (2023) "Mixotrophy of Algae: More Algal Biomass and More Biofertilization for Plants," *Sustainability*, 15(7), p. 5815. Available at: https://doi.org/10.3390/su15075815.

[89] Shankaran, P.I. and Kumari, P. (2024) "Nutritional Analysis of Plant-Based Meat: Current Advances and Future Potential," *Applied Sciences*, 14(10), p. 4154. Available at: https://doi.org/10.3390/app14104154.

[90] Sharma, R., Garg, P., Kumar, P., Bhatia, S.K. and Kulshrestha, S. (2020) "Microbial Fermentation and Its Role in Quality Improvement of Fermented Foods," *Fermentation*, 6(4), p. 106. Available at: https://doi.org/10.3390/fermentation6040106.

[91] Sim, S.Y.J., Srv, A., Chiang, J.H. and Henry, C.J. (2021) "Plant Proteins for Future Foods: A Roadmap," *Foods*, 10(8), p. 1967. Available at: https://doi.org/10.3390/foods10081967.

[92] Singh, B.P., Bangar, S.P., Alblooshi, M., Ajayi, F.F., Mudgil, P. and Maqsood, S. (2022) "Plant-derived proteins as a sustainable source of bioactive peptides: recent research updates on emerging production methods, bioactivities, and potential application," *Critical Reviews in Food Science and Nutrition*, 63(28), pp. 9539–9560. Available at: https://doi.org/10.1080/10408398.2022.2067120.

[93] Spendrup, S. and Hovmalm, H.P. (2022) "Consumer attitudes and beliefs towards plant-based food in different degrees of processing – The case of Sweden," *Food Quality and*

Preference, 102, p. 104673. Available at: https://doi.org/10.1016/j.foodqual.2022.104673.

[94] Sridhar, K., Bouhallab, S., Croguennec, T., Renard, D. and Lechevalier-Datin, V. (2022) "Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception," *Critical Reviews in Food Science and Nutrition*, 63(30), pp. 10483–10498. Available at: https://doi.org/10.1080/10408398.2022.2081666.

[95] Tan, Y.Q., Ong, H.C., Yong, A.M.H., Fattori, V. and Mukherjee, K. (2024) "Addressing the safety of new food sources and production systems," *Comprehensive Reviews in Food Science and Food Safety*, 23(3). Available at: https://doi.org/10.1111/1541-4337.13341.

[96] Thakur, A. (2019) "Market for Plant-Based Meat Alternatives," in *Advances in business strategy and competitive advantage book series*, pp. 218–237. Available at: https://doi.org/10.4018/978-1-5225-7350-0.ch012.

[97] Thavarajah, D., Lawrence, T., Boatwright, L., Windsor, N., Johnson, N., Kay, J., Shipe, E., Kumar, S. and Thavarajah, P. (2023) "Organic dry pea (Pisum sativum L.): A sustainable alternative pulse-based protein for human health," *PloS One*, 18(4), p. e0284380. Available at: https://doi.org/10.1371/journal.pone.0284380.

[98] Tireki, S., Balkaya, M., Erdem, D.E., Coskun, G., Gunay, E. and Cekirge, M. (2024) "A Review on Sensory Parameters and Evaluation Methods of Plant-Based Protein Foods," *Food Reviews International*, pp. 1–20. Available at: https://doi.org/10.1080/87559129.2024.2370944.

[99] Toutirais, L., Walrand, S. and Vaysse, C. (2024) "Are oilseeds a new alternative protein source for human nutrition?," *Food & Function*, 15(5), pp. 2366–2380. Available at: https://doi.org/10.1039/d3fo05370a.

[100] Tran, E., Dale, H.F., Jensen, C. and Lied, G.A. (2020) " Effects of Plant-Based Diets on Weight Status: A Systematic Review ," *Diabetes, Metabolic Syndrome and Obesity*, Volume 13, pp. 3433–3448. Available at: https://doi.org/10.2147/dmso.s272802.

[101] Trautwein, E.A. and McKay, S. (2020) "The Role of Specific Components of a Plant-Based Diet in Management of Dyslipidemia and the Impact on Cardiovascular Risk," *Nutrients*, 12(9), p. 2671. Available at: https://doi.org/10.3390/nu12092671.

[102] Tziva, M., Kalfagianni, A., Negro, S. and Hekkert, M. (2023) "Plant-based protein products in the news: Mind the gap between innovation and public discourses," *PLOS Sustainability and Transformation*, 2(1), p. e0000044. Available at: https://doi.org/10.1371/journal.pstr.0000044.

[103] Van Der Heijden, I., Monteyne, A.J., Stephens, F.B. and Wall, B.T. (2022) "Alternative dietary protein sources to support healthy and active skeletal muscle aging," *Nutrition Reviews*, 81(2), pp. 206–230. Available at: https://doi.org/10.1093/nutrit/nuac049.

[104] Vatansever, S., Tulbek, M., Riaz, M. and Mian, N. (2020) "Low- and High-Moisture Extrusion of Pulse Proteins as Plant-Based Meat Ingredients: A Review," *Cereal Foods World*, 65(4). Available at: https://doi.org/10.1094/cfw-65-4-0038.

[105] Walther, B., Guggisberg, D., Badertscher, R., Egger, L., Portmann, R., Dubois, S., Haldimann, M., Kopf-Bolanz, K., Rhyn, P., Zoller, O., Veraguth, R. and Rezzi, S. (2022) "Comparison of nutritional composition between plant-based drinks and cow's milk," *Frontiers in Nutrition*, 9. Available at: https://doi.org/10.3389/fnut.2022.988707.

[106] Wang, Y., Tuccillo, F., Lampi, A., Knaapila, A., Pulkkinen, M., Kariluoto, S., Coda, R., Edelmann, M., Jouppila, K., Sandell, M., Piironen, V. and Katina, K. (2022) "Flavor challenges in extruded plant-based meat alternatives: A review," *Comprehensive Reviews in Food Science and Food Safety*, 21(3), pp. 2898–2929. Available at: https://doi.org/10.1111/1541-4337.12964.

[107] Webber, J. (2021) "Vegan Burgers Arrive At Over 3,000 Hospitals And Schools," *Plant Based News*, 8 July. Available at: https://plantbasednews.org/lifestyle/food/vegan-burgers-morningstar-hospitals-schools/.

[108] Wilcox, A., Shurtleff, Aoyagi, Byrd, Fusaro and Forgrieve (2023) *Analysis of Leading Innovators in the Plant-Based Meat Alternatives Market*, *Morningside Review*.

[109] Yao, D., Zhou, J., Zhang, A., Wang, J., Liu, Y., Wang, L., Pi, W., Li, Z., Yue, W., Cai, J., Liu, H., Hao, W. and Qu, X. (2023) "Advances in CRISPR/Cas9-based research related to soybean [Glycine max (Linn.) Merr] molecular breeding," *Frontiers in Plant Science*, 14. Available at: https://doi.org/10.3389/fpls.2023.1247707.

[110] Younis, K., Ashfaq, A., Ahmad, A., Anjum, Z. and Yousuf, O. (2022) "A critical review focusing the effect of ingredients on the textural properties of plant-based meat products," *Journal of Texture Studies*, 54(3), pp. 365–382. Available at: https://doi.org/10.1111/jtxs.12704.