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Legume-Based Meat Analog Products: A Comprehensive Analysis of Nutritional and Technological Aspects

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Abstract: This review provides an in-depth analysis of the nutritional and technological features of legume-based meat analogue products, shedding light on their potential to address the rising demand for plant-based meat alternatives. Recognizing the high nutritional value, environmental benefits, and culinary adaptability of legumes, the study highlights their prominence as a viable option. It emphasizes that plant-based meat and meat analogues derived from legumes are pivotal in facilitating the transition away from animal-based products. Notably, the analysis underscores that plant-based meat offers a comparable amino acid profile to animal meat, making it a noteworthy substitute.Discover how 3D printing transforms meat alternatives by providing custom textures and ingredients. Witness the transition from the ecological footprint of traditional meat production to the sustainability of meat substitutes, which reduces greenhouse gas emissions, land consumption, and biodiversity loss. Furthermore, the study emphasizes the broader societal benefits, including accessibility to quality nutrition in underserved areas. By exploring the nutritional composition of legumes, the paper underscores the cost-effectiveness and holistic nutritional value of plant-based meat analogues (PBMAs). Despite these advantages, consumer scepticism persists due to limited awareness of PBMAs and a prevailing preference for conventional meat products. The review advocates for a comprehensive understanding and wider acceptance of PBMAs, foreseeing a promising future for their integration into the regular diets of consumers.

Keywords: PBMAs (Plant Bases Meat Analogues), Meat, Legumes, protein content,prospect of Meat analogues.

1.Introduction

The estimated population of our planet Earth will be around 9.8 billion by 2050 which is a significant concern. Such expansion in human population with limited resources will weigh upon nature and our environment. Compared to this date, demand for vegetarian food and meat will rise to 50% and 70% respectively(Kurek et al., 2022). Such a rise in meat consumption is not only

harmful to human health but also environment. Meat consumption also adds some health risk factors. For example: Red meat consumption results in cardiovascular diseases, and there are reported cases of liver fluke disease after consumption of pig meat (pork), Avian flu from Chicken etc (Fegan et al., 2022). Cruelty to animals is also a big factor in transitioning from meat to other protein sources. By 2050, demand for products that come from animals is projected to be 70% higher than it is now, due to the increasing global population, increasing income, and urbanization (Erdaw and Beyene, 2022). For thousands of years, meat has been an essential part of human diets and civilizations, giving nutrition, flavour, and adaptability to a variety of culturally and gastronomically diverse meals (Surya et al., 2022). Meat is considered an important protein source and appreciated for its taste, and texture other animalproducts like poultry and dairy are not considered as meat (Zhang et al., 2023). There are different definitions given for meat based on applications. Meat is any edible portion of animal tissue that has been slaughtered for food (Haase et al., 2023).Its complex composition of nutrients consists of high protein content and essential amino acids. However, the epidemiological correlation between eating red meat and processed meat with certain illnesses, such as colon cancer and cardiovascular issues, is concerning in terms of public health (Aveta et al., 2022).

One of the main concerns of increasing demand for plant-based meat substitutes is growing awareness of the environmental impact of conventional meat consumption (Andreani et al., 2023). Animal husbandry is linked to high levels of emission of greenhouse gases, deforestation, and insufficient use of water (Raihan et al., 2023). Plant-based meat analogues are often lower in saturated fat and cholesterol than typical meat products (Yang et al., 2023). They can also include important nutrients such as fibre and plant-based protein, making them a better option for consumers (Perez-Rodriguez et al., 2023). Plant-based meats allow people to experience similar flavours and textures without contributing to animal misery.

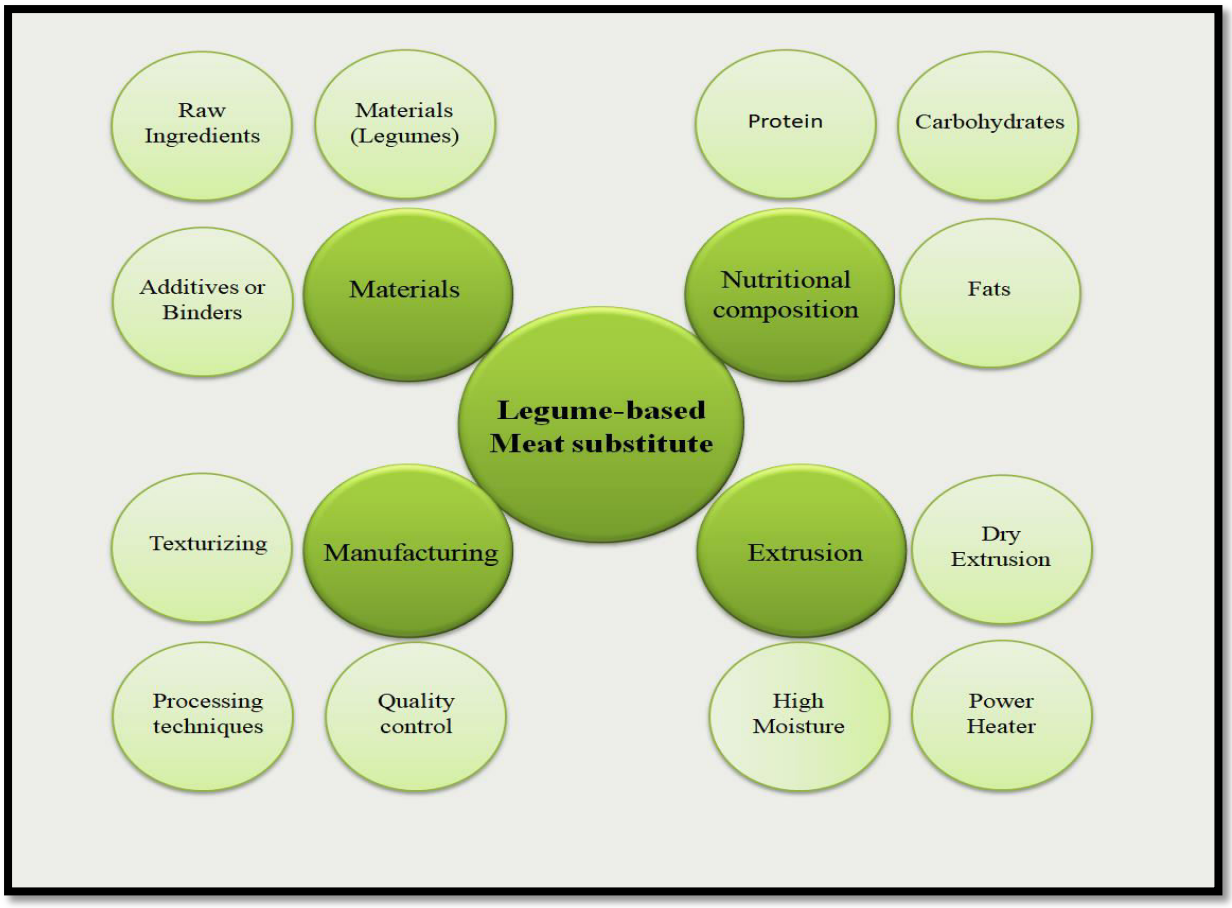

Figure: 1 Legume-based meat substitutes

2. Nutritional composition of legumes

Legumes constitute 27% of the primary food produced worldwide, which renders them the most significant crop plant in agriculture (Kebede et al., 2020). Legumes are an essential and viable source of protein, dietary fibre, vitamins, minerals, carbohydrates and photochemical (Jha and Jain, 2023).Over 19,000 species make up the fascinating botanical family of legumes, which includes widely grown crops like lentils, beans, peas, soybeans, and peanuts (Boukid et al., 2019). Legumes (Fabaceae) make up one-third of the protein in the average person's diet and are the second-most significant crop plant in agriculture after cereals. Following oilseeds and cereals in terms of crop production globally, legumes rank third (Mbava et al., 2020). Legumes are occasionally referred to as "poor man's meat" since they are an important source of protein in the human diet (Ferreira et al., 2021). Here, we give a brief overview of the nutritional makeup of a variety of popular legumes, including chickpeas, peas, lentils, beans and soybeans.

Table 1: Nutrient composition and processing of the most-consumed legumes (g/100 g)

Legumes	Botanical name	Proteins	Carbohydrates	Fibre	Lipids	Calories	References
Chickpea	Cicerarierinum	23.6	62.3	3.8	6.4	164	Emir et al., 2023
Pea	Pisumsativum	21.9	52.5	10.4	2.3	81	Nestel MD et al., 2021
Lentil	Lens culinaris	20.6	56.4	6.83	2.15	110	Emir et al., 2023
Bean	Phaseolus vulgaris	21.3	47.8	18.4	1.7	140	Raihan et al., 2023
Soybean	Glycine max	36.9	6.1	20.9	18	174	Raihan et al., 2023

3. Formulation of meat analogue products

In Western nations, consumer preference research revealed that meat consumers are more inclined to switch to plant-based meat analogues when the product mimics meat in texture, consistency and sensory qualities and can be accommodated into a meal set that satisfies the consumer's expectation (Kyriakopoulou et al., 2021). Recent meat analogue research and development targets the creation of ethical products that mimic traditional meat not just nutritionally, but also in all of its physical aspects such as texture, look, taste andsmell.

3.1 Emulsion-type products

Plant-based meat analogue products like sausages, bologna, mortadella, etc. are examples of emulsion-type products. Emulsion-type meat analogues are intended to have the texture and mouthfeel of ground meat items like ground beef or sausage (Kurcubic et al., 2022). They're famous for their juiciness and adaptability, making them ideal for burgers, sausages, and meatballs.Many plant-based emulsion-type meat analogue products are influenced by meat and meat extender applications in which high protein non-meat substances partially replace meat (Pintado and Delgado-Pando, 2020).

3.1.1 Protein: Soy protein, wheat gluten, pea proteins, and mycoprotein (derived from fungi) are just a few of the plant proteins that may bind water and stabilise emulsions and gels.These proteins provide the texture and consistency necessary to mimic meat properties. To create a coarser texture in these formulations, it is also common to add texturized proteins (Ozturk and Hamaker, 2023).

3.1.2 Binding agents: To achieve meat meat-like texture various soluble binders such as soy protein isolate, methylcellulose and modified starches are used. The role of these binders is to enhance the textural properties of the products by providing the desirable thickeningAdditionally, these ingredients contribute to emulsion stability and reduce oil leakage.

3.1.3 Fats: Fats are a crucial component in emulsion-type meat analogue products to improve the tenderness, juiciness and overall palatability of products. They can help to generate a familiar sensation in meat analogues (Aydar et al., 2023). Vegetable oils (e.g., soybean, coconut) and solid fats like coconut oil are typical fat sources utilized in meat analogues. The type of fat might affect the texture and flavour characteristics of the final product.

3.1.4 Colorants: Colorants are also used to give meat analogues a natural appearance that matches real meat. Myoglobin is a protein present in the meat that gives colour to meat. Plant-based meat analogues usually lack myoglobin, so colourants are used to make the emulsion-type product more appealing. For example, caramel colour is used to make the product darker.

3.1.5 Spices: Spices are vital for flavouring meat substitutes, as they help simulate the taste of genuine meat. Salt is one of the most significant taste enhancers. However, when it comes in touch with proteins, it affects their functions.

3.2 Chicken like products

Another type of plant-based meat analogue product aims to replicate whole-cut meats, such as chicken, beef steaks and pork, which have complex fibres or a layered structure (Wang et al.,2023). Extrusion is the primary method used to create plant-based meat analogues that replicate this fibrous structure. These products are processed further by curing, freezingmarinating and then cooking to obtain the required final structure, colour, tenderness, fragrance, and flavour modifications.

3.2.1 Protein: Soy protein is one of the most often used components in a variety of products. In addition to its isolated form, less processed variations, such as concentrates, are often used in extrusion processes. To form multi-phase blends, isolates are sometimes combined with extra components such as wheat gluten or carbohydrate fibres (Sengar et al., 2023).

3.2.2 Binders: In contrast to the earlier kinds of meat analogues, which frequently count on binders to keep their constituents together, binders are not often needed in whole-cut-type meat analogues. Whole-cut meat analogues leadtoimitating the experience of eating full pieces of meat, such as steaks or chicken breasts, instead of minced or ground meat (Frank et al., 2022).

3.2.3 Fat: Fat is integrated to a limited level during the structure step, and texturized goods can be supplemented with more fat later on, generally by margination (Weiss et al., 2010). The industry normally prefers liquid oils for these sorts of products. Nonetheless, a study into potential enhancements is underway, particularly for items that resemble raw steak-like portions, where the integration of marbling effects may be desirable.

3.2.4 Colouring agents and flavours: Salt is one of the most important taste enhancers in plant-based meat analogues. In the case of taste advancement, the marination process by infusion is more successful if the wet extrudate product is frozen and then thawed prior to diffusion (Kyriakopoulou et al., 2021).

3.3 Texturized vegetable protein

TVP is a food with high protein content made from soybeans or other plant-based sources. Because of its high level of protein content, cost-effectiveness, and versatility in many dishes, it has gained preference as a flexible meat alternative, particularly among vegetarians and vegans. TVP is well-known for its ability to simulate the texture and look of meat, making it a lucrative component in the food business as well as a mainstay in many vegetarian and vegan diets. Extrusion is the process by which TVP is manufactured. High heat and pressure are applied to the dough, causing it to expand and take on a fibrous, meat-like texture (Balestra et al., 2019).

4. Vegetarian meat ingredient

While the initial plant protein component selection serves as the foundation for product development, the final choice is frequently impacted by factors such as protein availability, crop yields, and protein extraction capabilities. Soybean meals, for example, were traditionally used as animal feed after being left over from oil production. There is one more common component wheat protein, which consists of an elevated amount of gluten. When gluten is used in meat substitutes, it shows unique film-forming capabilities that result in fragile fibres (Zhang et al., 2022). Furthermore, it is cost-effective as the starch that exists in wheat flour is also used in industry. The major disadvantage is that some people are gluten-allergic. Along with gluten and soy protein,otherprotein-rich oilseeds and residues from oil production are also examined as ingredients of plant-based meat analogues, for example, sunflower oil and rapeseed.In the following sections, we will explore ingredients for the two meat analogue categories: emulsion and muscle-type products(Schreuders et al., 2021).

4.1 Soy protein

Soybeans (Glycine max) are leguminous crops mainly identified for their culinary applications. They are employed in many kinds of products, including tofu, fermented foodsand soymilk.Soybeans, on the other hand, have recently

acquired prominence as an economically feasible and high-quality source of vegetable protein for consumers.Soybeans contain both water-soluble and insoluble proteins(Bueno et al., 2020).

Soy protein isolates and concentrates are some of the most used components in the manufacture of meat substitutes such as burgers, sausages, and muscle-like meat replacements. Table 2 summarises the functional quality and application possibilities of several soy components as well as other protein-rich substances. For TVP-based patties, stronger blends of soy protein isolate and gluten or soy protein concentrate have been employed, while less refined components have also been used for soy emulsions and gels for sausages.

Table 2: Non-protein ingredients and sources found in commercial plant-based meat substitute products

Ingredients	Sources	Primary function	References
Non-animal protein	Soy protein, wheat gluten, legumes, peas, lupin, and rice	Enhance nutrition, provide structure, colour, texture, and flavour tech-functional properties	(Li et al., 2022
Fats	Coconut oil, cocoa butter, corn oil, soybean oil, sesame oil, sunflower oil	Contribute to mouth feel, texture, flavour and nutrition	(Li et al., 2022
Polysaccharides	Flours Native starches Fibres	Ensure consistency Water binding	(Thaweewong and Anuntagool, 2023)
Vitamins	Riboflavin, thiamine, niacinamide, folic acid, vitamin B6 and vitamin B12	To reduce the deficiencies and supplement vitamins	(Wu et al., 2020)
Minerals	Calcium chloride, calcium phosphate, sodium phosphate, iron, sodium chloride and potassium chloride	To increase water holding capacity and nutritional value	(Wang et al., 2023)

4.2 Wheat gluten

Wheat gluten is one of the main components for the production of plant-based meat analogues. It is cost-effective because it is a by-product of the manufacturing of wheat starch.Unlike soy, wheat gluten extraction requires separating the soluble and dispersible components from the insoluble protein using only water as a solvent. Wheat gluten delivers more than simply adhesiveness and dough-forming capabilities; it additionally offers beneficial properties such as viscosity, swelling, and improved nutritional content(Uthayakumaran and Wrigley., 2010). Wheat gluten is flexible due to its unusual properties since it can act as both a binder and a structuring agent.

4.3 Legume protein

Extensive research has been carried out on the functional qualities of legume proteins produced from a wide range of sources, including peas, lentils, chickpeas, faba beans, mung beans, and other forms of legumes. Major proteins present in legumes have different functional properties, these properties play an important role in the development of creative food ingredients and the formulation of many different protein-rich food products (Boye et al., 2010). Solubility, water-holding capacity, emulsifying ability, foaming, and oil absorption are the most significant functional properties that help to examine the functional behaviour of each protein.Among all of the plant proteins available, pea protein has gained a lot of attention(Boukid et al., 2021).

5. Processing techniques

Many processing methods for plant-based meat substitutes have been developed, whether they mimic whole-muscle qualities or include reformed formulations, with a major focus on mimicking desired textures.In the late 1960s, extrusion technology revolutionised the manufacture of textured plant-based protein, opening up new possibilities for making meat analogues. Solvent-extracted defatted soy flour, which generally contained roughly 50% protein, was one of the principal raw ingredients utilised at that time (Gulkirpik et al., 2023).

5.1 Extrusion

Extrusion cooking is defined as "the process of plasticizing moistened, expansile, starchy materials in a tube using a combination of moisture, pressure, heat, and mechanical shear." This causes the product temperature to rise within the tube, gelatinization of starchy components, protein denaturation, stretching or restructuring of tractile components, and exothermic expansion of the extrudate. The extrusion process is critical in the manufacture of plant-based meat analogues, assisting in the transformation of a combination of plant materials into a product with a consistency that resembles meat and appearance.There are

basic extrusion techniques that are used for the production of the plant-based meat analogue:

1. Dry extrusion process
2. Wet extrusion processing (High moisture)
3. Power heater extrusion processing (Thermal extrusion)

Due to a number of compelling criteria, dry extrusion processing is the most often used technology for producing texturized proteins (Luo and Koksel., 2023). This procedure typically begins with raw materials possessing moisture levels ranging from 20% to 35%. The first stage comprises the delivery of raw materials, which are normally provided in bulk. After obtaining the raw ingredients, they are combined and transported to the subsequent processing methods. Its extrusion component includes critical components such as a feed bin with an integrated feeder, a preconditioner, an extrusion cooker, and a die-knife assembly. Each of these components has been precisely created to have a distinct role in the texturization of vegetable-based dietary proteins.

The wet extrusion processing method is used for making texturized products and is frequently referred to as HME (high-moisture extrusion), or HMMA (high-moisture meat analogues). This method begins with extrusion, which entails pushing a food combination through specially built equipment known as an extruder. The semi-liquid or high-moisture food material is put into the extruder.Because of the revolving screw, the food material is subjected to extreme pressure and shear stresses as it is forced through the extruder. Furthermore, heating devices are often installed throughout the barrel of the extruder, allowing for fine adjustment of the temperature (Sengar et al., 2023).

Thermal extrusion, a well-established and highly studied process, is still commonly used. Nonetheless, several additional ways to create muscle fibre mimics have evolved, including wet spinning,conical shear and electrospinning. Thermo-extrusion is a processing technique in which a combination of components is forced through specifically built machinery known as an extruder. Plant proteins, combined with additional substances such as water, lipids, and spices, are processed using this technique in order to generate a textured and meat-like structure (Tan et al., 2023).

5.2 3D Printing

The 3D printing technology is also known as fused deposition modeling (FDM), is one of major type of additive manufacturing that involves other types, such as selective laser sintering and stereo lithography.3D printing technology may be applied to the food manufacturing industry to build complex structures and patterns with fine control over texture and content, including meat substitutes (Portangues et al., 2019). Like meat substitutes, 3D printing enables product customization to meet individual preferences and tastes.For 3DP, a variety of

materialsexist that include polymers, ceramics, metals and biomaterials. This type of additive manufacturing hasbeen identified as a promising manufacturing process in various industries that involves the food industry.This technology offers opportunities for innovation and creativity in the development of meat alternatives.

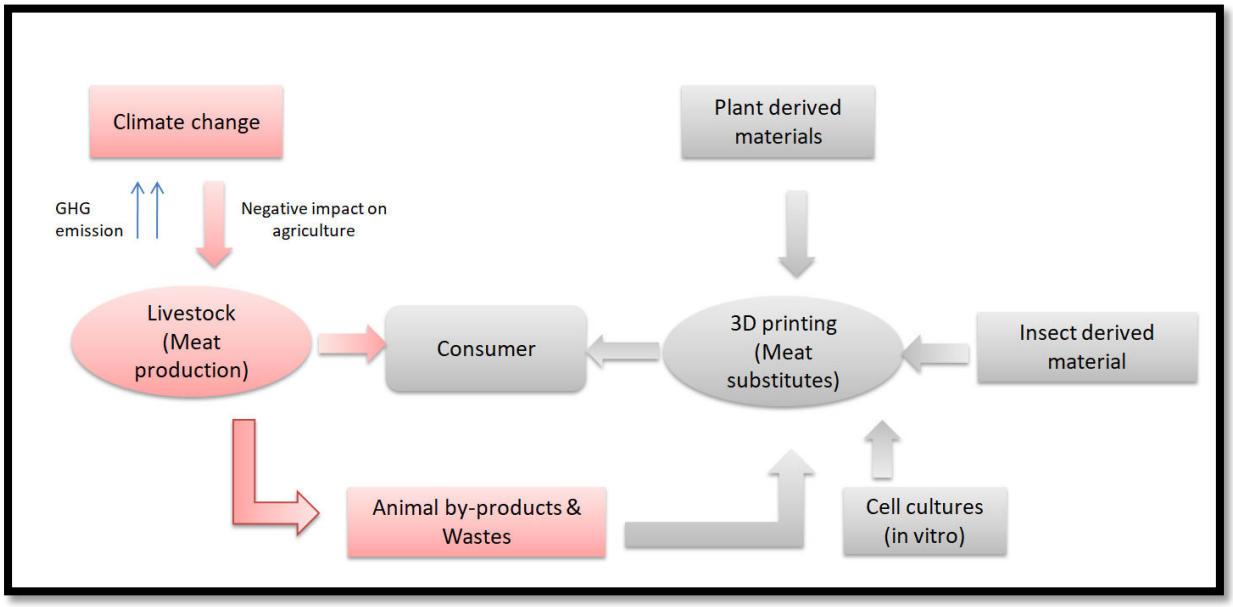

Fig 5: Systematic illustration of 3DP of meat substitutes

6. Environmental footprint of meat production:

The production of meat has a substantial impact on a number of environmental problems, such as deforestation, water and land usage, greenhouse gas emissions, and biodiversity loss. Understanding the environmental impact of meat production is essential for solving sustainability issues and making the shift to more ecologically friendly food systems as the world's demand for meat rises. We will examine the various environmental effects of meat production, including how it affects biodiversity, water resources, land usage, and climate change.

6.1 Greenhouse Gas Emission:

The production of meat contributes significantly to greenhouse gas emissions, especially nitrous oxide and methane, both of which are strong drivers of climate change. Methane is emitted during enteric fermentation and waste management by livestock, especially cattle, whereas nitrous oxide is created following fertilizer application during feed production (Kabange et al., 2023). The cattle industry is a major contributor to climate change, accounting for around 14.5% of worldwide anthropogenic greenhouse gas emissions, according to the Food and Agriculture Organization.

6.2 Biodiversity loss:

Threats to biodiversity include habitat degradation, species extinction, and land-use changes brought about by the rise of livestock production. Important animal habitats are lost as a result of deforestation for pastureland and feed crop development, and extensive livestock production methods can contaminate and degrade natural areas (Bodo et al., 2021). Livestock overgrazing may also upset ecosystems, decreasing biodiversity and changing natural processes.

7. Market Trends and Future Directions:

Legume-based meat substitutes have emerged as a key factor in the changing landscape of plant-based meals, impacted by a variety of market trends and future paths. This inventive industry is growing rapidly because of altering customer tastes, technology breakthroughs, and a greater emphasis on health and sustainability.

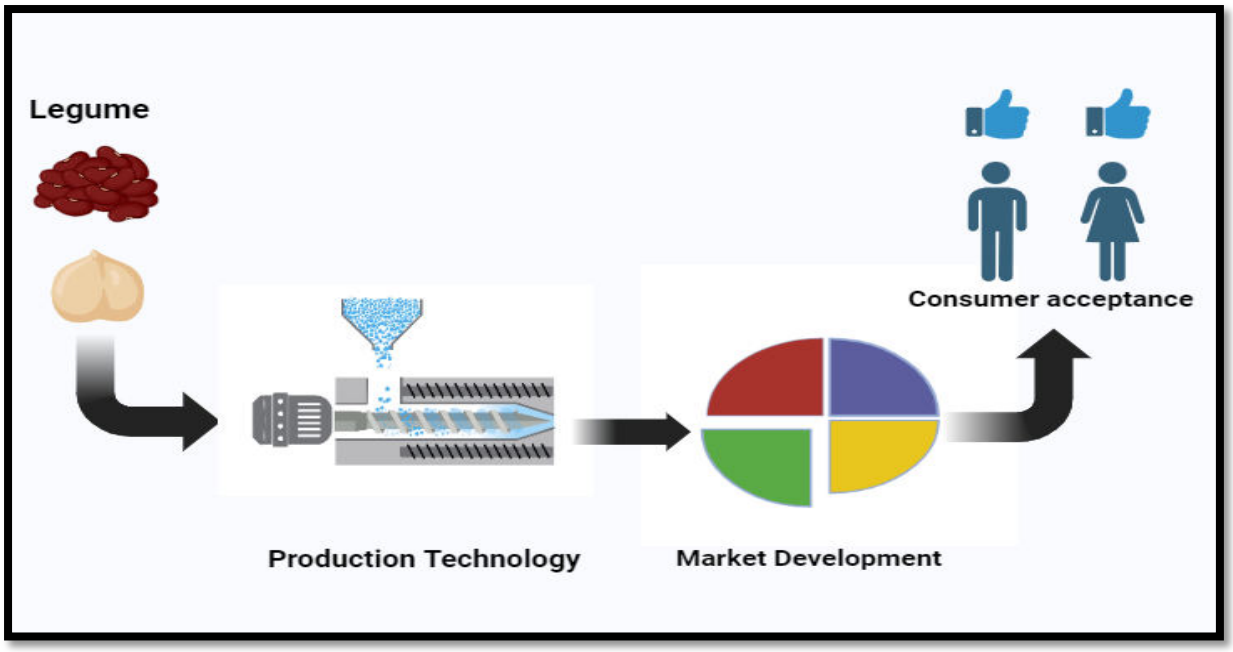

Figure 7: Consumer acceptance

7.1 Current market trends

The present market for meat analogues is seeing significant growth due to a variety of variables. With a growing emphasis on health and well-being, people are looking for alternatives to conventional meat, resulting in a surge of interest in plant-based diets. Technological improvements have aided in the development of increasingly complex and appealing meat substitutes that closely replicate the flavour and feel of genuine meat, hence increasing consumer acceptability. Companies are broadening their products, employing diverse

plant sources to develop a broader selection of meat substitutes that are now more widely available in retail and food service venues (Swann and Kelly., 2023).

7.2 Area of future research

Texture improvement research is promising, with the goal of achieving a meat-like mouthfeel through enhanced protein structure and emulsification processes. To assure the widespread availability and affordability of legume-based meat analogues, cost-cutting measures and scaling solutions are required. In-depth consumer research is required to identify preferences, cultural biases, and hurdles to acceptance, allowing for specialized product creation and effective marketing methods.

8. Conclusion

This Comprehensive study on Plant-Based Meat Analogues (PBMAs) showcases that it is the best alternative of traditional meat. Legume and cereal-based protein products offer a valuable choice for both vegetarians and traditional meat consumers. It has shown itself a viable option for those who are looking for a reduction in meat consumption without compromising the actual taste, texture and nutritional profile.**T**he accessibility and affordability of these PBMAs are not for a larger population but larger companies and Industries are investing their time and money to improve the technology and make it more affordable and accessible for a larger population.As knowledge of the health gains linked with reduced meat consumption continues to gain potential, the PBMA industries stand to play a pivotal role in fostering healthier dietary habits globally. As this continues to evolve and innovate, it holds the potential to not only revolutionize the food industry but also contribute to the broader goal of fostering a more sustainable and compassionate global food system.

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