PLANT-BASED PROTEIN: A WAY FORWARD FOR NUTRITION SUSTAINABILITY

Abstract

In recent years, plant-based proteins are gaining much more importance for various reasons. Traditionally, nuts and leguminous crops were considered natural sources of plant proteins. With the advancement of extraction technologies, proteins are derived from a wide range of cereals, vegetables, vegetable seeds, algae, and other edible seeds, which can be alternative protein sources. Besides, the antinutritional factors associated with legume crops are taken care of to provide a portion of sustainable and holistic food to the population. Furthermore, some traditional processes like fermentation are ways to minimize the health deterrent factors associated with plant-based proteins. Plant-based proteins are not confined to the milk and meat analogs anymore; they now constitute a part of the customized diet or designer foods for different age groups and professionals, in the form of protein concentrates, isolates and hydrolysates. The global market for plant-based protein has seen exponential growth post-COVID times, and several major players are in the research and development of plant-based protein. Considering that a large section of the global population is still striving for nutritional security, the availability of these plant-based proteins will pave the way for meeting healthy body and soul requirements in this dwindling climatic condition.

Keywords: Plant-based proteins, Milk and meat analogues, Fermentation, Edible film

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I. INTRODUCTION

The human body requires different nutrients (water, carbohydrates, protein, fat, vitamins, and minerals) to perform its essential functions. Most of these nutrients provide energy, contribute to the body's structure, and maintain chemical processes in the body. Among these nutrients, proteins are vital as they provide structural and functional support. They also aid in building and repairing tissues. In the human body, proteins cannot be stored; thus, it needs to be included in our everyday diet to meet our daily requirements. Amino acids, the building blocks of proteins, can be classified into non-essential and essential amino acids. The non-essential amino acids are synthesized inside the human body, while essential amino acids are not. These essential amino acids can only be obtained by consuming various protein-rich foods. These protein-rich sources can be differentiated into animal-based and plant-based. Even though most important amino acids are fulfilled from animal sources, the change in consumer preferences led to exploring other protein sources. Since the “Go Vegan” initiative and “Sustainable Production of Food” are trending, plant-based protein is gaining popularity among consumers.

There are many reasons for changing the mindset of consumers toward plant protein. The first significant perspective for shifting consumer preference toward plant-based proteins is that around 2 to 15 kg of plant foods are required to produce 1 kg of meat (Aiking *et al.*, 2011). Second, many diseases are spreading through animals, like swine flu, bird flu, foot and mouth infections, *etc.*, which are life-threatening and put the onus on the economy, apart from damaging the environment. Third, methane produced by livestock, especially ruminant animals, is crucial to both global warming and the ozone layer's depletion. Additionally, ruminant energy losses from methane generation are significant, which lowers productivity and energy gain. Fourth, as meat and dairy production needs to be doubled to meet the anticipated protein demand in 2050, the environmental impact of livestock must be reduced by half to the current level of ecological damage (de Bakker and Dagevos, 2012). This has forced the consumer to search for another probable source of proteins. Fourth, plant-based nutrition can be considered the best dietary approach for ensuring holistic nourishment and longevity for the body. Fifth, the knowledge of the advantages of plant-based protein consumption continues to provide the food industry with new marketing options (Manickavasagan *et al.*, 2022). Even though many plant-based proteins are regularly consumed in our day-to-day diet, the availability of modified forms of these proteins, such as protein isolates, concentrates, and hydrolysates, which have higher digestibility than the original foods, has led to the evolution of designer foods and the replacement of proteins such as whey protein, egg protein, and other proteins from animal sources. The demand for new plant-based proteins is influenced by consumer trends and aspects such as price, availability, compatibility for incorporation into new products, and, most significantly, functional qualities. Lastly, some people’s perspective is based on religious and cultural beliefs and feel animal slaughtering signifies cruelty. Therefore, many value-added products have been formulated from plant-based proteins like milk and meat analogues, fermented derivatives and beverages, edible films, protein-enriched and fortified foods, *etc.*

Animal milk is considered wholesome food providing macro and micronutrients, which help grow and maintain the body. Still, lactose intolerance is rapidly spreading globally, particularly among the elderly. Moreover, in some areas like arid regions, milk availability is limited. At the same time, it is expensive for some sects of the population and may be harmful due to some pathogens (*Salmonella spp.* and *Escherichia coli*). Additionally, the environmental impact of producing milk in terms of land, energy, and other resources required to produce milk of animal origin is very high compared to producing plant-based milk substitutes. Therefore, the demand for milk alternatives/milk substitutes/milk analogues is increasing among people with dietary restrictions brought on by allergies, lactose intolerance, or a particular diet, and vegetarians, vegans, and flexitarians.

Meat products have high biological protein values, vitamins, and minerals. However, it is generally known that meat has a high cholesterol content and a more significant proportion of saturated fatty acids than polyunsaturated fatty acids, which have been strongly associated with many disorders that have reached epidemic levels. Therefore, there is a continual increase in consumer demand for meat substitutes due to consumer demand for healthy diets, concern over rising meat prices, growth in popularity of vegetarianism, and growing consumer interest in eating behaviors like avoiding or lowering intake of red meat. It's also intriguing to employ a different source, such as plant protein, as a component of human meals.

Annually, the agro-food industry produces over 190 million tonnes of by-products like leaves, stalks, shells, seeds, bran, oil cake, molasses, *etc.* (Kumari *et al.*, 2018). Several agro-food industrial by-products contain high levels of proteins, lipids, and other bioactive substances such as pigments, alkaloids, dietary fibers, and phenolics (De Los *et al.*, 2018). Techniques for recovering proteins from by-products of plant origin have become popular recently among scientists working in various sectors, particularly in industrialized and developing nations.

Edible films can be produced with lipid, carbohydrate, and protein components. The twenty different amino acids and their combination provide various unique structures to other protein-based compounds, thus conferring the edible films a more comprehensive range of functional abilities, including a high intermolecular binding potential. In addition, they have better mechanical qualities than polysaccharides and fat-based edible films (Cuq *et al.*, 1995). Protein-based films also exhibit superior gas barrier properties than those prepared from lipids and polysaccharides. Extruded snacks, morning cereals, pasta, snack bars, and chips are just a few examples of conventional food items that employ a range of plant-based protein ingredients, including concentrates and isolates from soy, pea, lupin, and lentils, among others.

II. PLANT-BASED PROTEINS V/S ANIMAL-BASED PROTEIN

The food providing the essential amino acids can be categorized into complete and incomplete protein sources. Most of the complete protein sources are of animal origin (like eggs, fish and seafood, lean meat, poultry, and dairy products). In contrast, plant-based sources (except soya protein) may lack a sufficient amount of one or more essential amino acids. The primary plant-based protein sources include cereals (wheat, rice, corn, barley, *etc.*), pulses (lentils, peas, beans, *etc.*), and oilseeds (canola, coconut, soybean, flax seed, *etc.*), respectively. However, the requirement of complete protein from plant sources can be fulfilled by consuming various protein-rich foods, *e.g.*, beans that are low in methionine and high in lysine can pair with barley and lentil soup. Getting all the required amino acids from plant-based sources can still be manageable but requires some effort.

Regarding the associated nutrient content of animals and plants, each has advantages over the other. For example, animal protein intake provides vitamin D, cobalamin, omega 3, zinc, heme-iron, menaquinone, *etc*. On the other hand, plant proteins have more nutrients like vitamin C, fiber, flavonoids, polyunsaturated fats, oligosaccharides, and carbohydrates. In addition, some studies have reported adverse health effects on the body, as animal protein sources contain saturated fat and a higher cholesterol level. Therefore, consuming a single source of animal protein can create problems in the human body. Also, the overall health of vegetarians is observed to be better than non-vegetarians.

III. SOURCES OF PLANT-BASED PROTEINS

There are different plant-based proteins; some provide all essential amino acids for the human body. In addition, there are various sources of plant-based proteins (Table 1).

Table 1: Plant-Based Proteins

Sl. No.	Protein source	Protein content	Brief description
1.	Soy-based proteins	Around 40 %	Considered a complete protein as it contains all the amino acids required for the human body. It is the richest source of protein in a plant-based diet.
2.	Nut based proteins	7.9 - 25.8 %	Leguminous crops are grown for their edible seeds as well as oil seeds.
3.	Lentils	Around 25 %	Edible legumes are high in fiber and carbohydrate content and low in fat content.
4.	Mycoprotein	Around 11 %	A fungus (*Fusarium venenatum*) used to produce meat substitutes.
5.	Spirulina	Around 5.9 % in raw; 50-70 % in of its dry weight	Green or blue algae with high protein content.
6.	Amaranth and quinoa	14.1 – 17 %	Complete plant-based protein.
7.	Hemp seeds	Around 10 %	Rich source of various nutrients and a complete plant-based protein. These seeds can be consumed raw or used to make milk, oil, cheese substitutes, and protein powder.
8.	Chia seeds	Around 16 %	Edible seeds of *Salvia hispanica*, a flowering plant in the mint family. They are rich in fiber and omega-3 fatty acids.
9.	Vegetables	2 – 8 %	Vegetables like spinach, broccoli, asparagus, artichokes, sweet potatoes, and Brussels are rich in protein.
10.	Nutritional yeast	Around 8 %	It is sold as a yellow powder or flakes derived from a deactivated strain of *Saccharomyces cerevisiae* yeast.
11.	Green peas	Around 5 %	Along with protein, it is also a good source of fiber, folate, manganese, Vitamin-A, Vitamin-C, and Vitamin k.
14.	Oats	Around 17 %	Edible seeds from the Poaceae grass family (*Avena sativa*).
15.	Spelt and teff	13 – 15 %	Spelt, also known as Dinkel wheat or hulled wheat is a grain species. Tef is a tiny nutritious seed that originates from an annual grass.
16.	Wild rice	Around 15 %	Wild rice contains more protein than other long-grain rice varieties.

(Source: Anonymous, 2022a)

IV. PROCESSING TECHNOLOGY AND METHODS OF EXTRACTION

Protein modification is a process of improving the bioactivity and functionality of protein by changing the structure of protein molecules. These modification methods are physical, chemical, and biological (Fig 1).

The protein extraction or purification process includes isolating and purifying one or a few proteins from a complex mixture. The protein extraction techniques improve extracted protein's yield and functional and nutritional qualities. Therefore, the proper method of extraction for increased efficiency should be chosen. Different protein extraction methods are delineated in Fig 2.

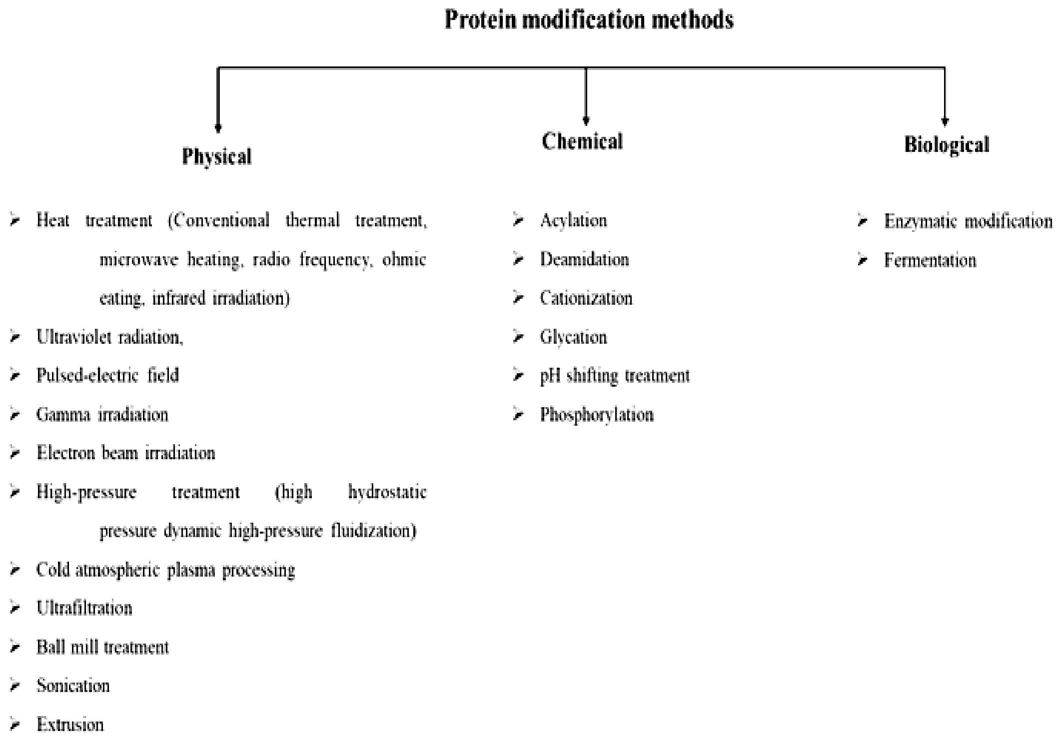

Figure 1: Different Protein Modification Methods.

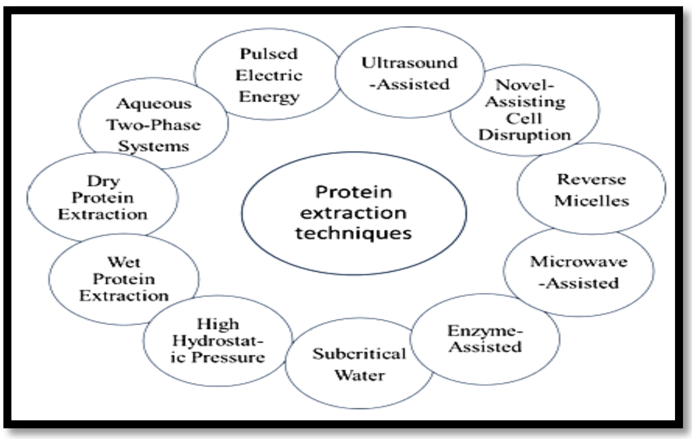

Figure 2: Different Protein Extraction Methods.

V. PROTEIN CONCENTRATE, ISOLATE, AND HYDROLYSATES FROM PLANT-BASED PROTEINS

Isolates are the most refined form of protein products containing more than 80 percent of proteins and no dietary fiber (Sim *et al.*, 2021). These are exceptionally easily integrated into many food items and are very digestible. They also offer the benefits of color, flavor, and functional qualities, which makes them a perfect component for drinks, baby foods, textured protein products, and several specialized food varieties. Plant-based protein isolates have been taken from various plant sources, including pinto, navy, other beans, sesame, cashew, peanut, and soybean. Isolates can be extracted using isoelectric precipitation, alkaline extraction, or ultra-filtration methods.

Protein concentrates are frequently created by eliminating non-protein ingredients, generally carbs, to increase the product's final protein concentration. These concentrates typically have a protein content of 50–60 percent. (Sim *et al.*, 2021). Making leaf protein concentration (LPC), the most popular plant protein, involves pulping young leaves and pressing the pulp. The isolated liquid fraction is subsequently separated from the leaf protein concentration (LPC) using filtering or centrifugation. Herbaceous plants and legumes like clover and lucerne produce protein concentrate with a higher yield. Although all LPCs require supplements because they are lacking in lysine and methionine, two essential amino acids, certain LPCs have protein qualities comparable to those of soybeans, the most protein-rich legume. Protein concentrates can be produced using these three methods: aqueous alcohol wash, acid wash, and water wash with heat denaturation.

Protein hydrolysates are a complex combination of small peptides and amino acids formed by protein degradation using enzymes, acids, alkaline treatment, or fermentation. Extraction of protein hydrolysates frequently employs alkaline and saline solutions. While purification utilizes dialysis, isoelectric, micellar precipitation, and ultrafiltration/diafiltration methods (Zhu *et al.*, 2010). The standard alkaline procedure is the conventional method for extracting protein, where the alkaline treatment forms precipitate. The protein extracts are then washed to eliminate contaminants (Mondor *et al.*, 2010). Finally, the yield protein hydrolysate is purified using dialysis or ultrafiltration methods (Chittapalo *et al.*, 2009). However, since alkaline treatment may result in unfavorable reactions, reduction in protein digestibility, and the loss of specific amino acids, novel technologies such as pulsed electric field, ultrasound, and microwave are used to increase extraction efficiency and provide minimally processed products.

VI. MILK ANALOGUES

Plants, like legumes, cereals, pseudo-cereals, and vegetables, are used to make commercial milk substitutes. Fermented plant-based milk's color and texture mimic animal milk; however, its natural makeup cannot be compared to cow's milk. Consequently, additional nutrients like vitamins, minerals, and vital amino acids are added to commercial plant-derived milk formulations (Sethi *et al.*, 2016). In addition, fermentation boosts the proliferation of fermenting food-grade bacteria and improves the solubility of plant proteins with higher amino acid availability and composition (Tangyu *et al.*, 2019). In mixed-culture fermentation, microbial interactions are mutualistic. At least one species of microorganism benefits from such an association by promoting or improving positive biological activity. For example, the proteolytic *Lactobacilli* strain ensures the release of peptides and amino acids during yogurt fermentation, while *Streptococcus* supplies growth-promoting ingredients like pyruvic acid, formic acid, and folic acid (Sieuwerts *et al.*, 2008). In addition to promoting microbial growth, mixed culture during fermentation also increases the generation of volatile compounds and acids, providing similar organoleptic and rheological properties to that of animal milk.

Cereals' appealing nutritional profile makes them a good candidate for the creation of fermented functional milk. A variety of micro and macronutrients in grains provides the environment necessary for developing lactic acid bacteria and improves the bioavailability of nutrients. For example, malted cereals, either by themselves or in combination with hydrolytic enzymes, boost the bioavailability of bound nutrients like proteins and carbohydrates (Luana *et al.*, 2014). In addition, high molecular weight polysaccharides produced by lactic acid bacteria increase the substrate's viscosity, a crucial component of the texture of yogurt and fermented beverages made from cereals.

Plant-based milk is high in fibers, isoflavonoids, antioxidants, monounsaturated, polyunsaturated fats, and free of lactose, cholesterol, and animal protein (Chalupa-Krebzdak *et al.*, 2018). This milk has possible antibacterial benefits and lowers the risk of cardiovascular diseases, low bone mass, and gastrointestinal disorders with better physiological functioning. In addition, the high levels of antioxidants with free radical scavenging properties improve the activity of bioactive components (Akin and Ozcan, 2017). Despite the benefits of plant-based beverages, these products have some disadvantages compared to milk. The drawback of plant-based beverages is their nutritional imbalance, which makes their prospection in the food market difficult (Vagadia *et al.*, 2018). Table 2 summarizes the types of plant-based milk analogues and their bioactive compounds, health benefits, and shelf life.

Table 2: Types of Plant-Based Milk Analogues

Product	Bioactive compounds	Health benefits	Shelf life	References
Almond milk	Vitamin E Niacin Stigmasterol folate β-sitosterol	• Low calorie • Probiotic • Powerful antioxidant	Refrigerated condition (4 ^{0}C): 170 days	Alozie & Udofia 2015; Bernat *et al.*, 2015a; Sethi *et al.*, 2016; Chhabra *et al.*, 2017; Gorji *et al.*, 2018; Lee *et al.* 2018; Iorio *et al.*, 2019.
Cocoa milk	Caffeine Theo bromine	• Anti-aging	Ambient condition (25-37^{0}C): 21 days Refrigerated condition (5-10 ^{0}C): Three months	Neti & Azhari, 2010; Maciel *et al.*, 2017.
Coconut milk	Vitamin E Lauric acid	• Anti-aging • weight loss • Boosts immune system	Refrigerated condition (4 ^{0}C): 30 days	Agarwal & Bosco, 2014; Sethi *et al.*,2016; Katz, 2018; Mauro & Garcia, 2019.

Hemp milk	Linolenic acid Linoleic acid Tocopherol	• Anti-inflammatory • Anti-thrombotic	Refrigerated condition (4 ^{0}C): 3 days	Teh & Birch 2014; Crescente *et al.*, 2018; Zhou *et al.*, 2018; Wang *et al.*, 2018.
Kidney bean	γ-aminobutyric acid (GABA) Dietary fibers	• Antioxidant • β-glucosidase activity	-	Limon, 2014; Kumar *et al.*, 2013.
Oat milk	Avenanthramides Phytochemicals β –glucan	• Decreases blood glucose level • Hypocholesterolemic • Anti-pathogenic effect	Refrigerated condition (4 ^{0}C): 28 days	Bernat *et al.*, 2015c; Sethi *et al.*, 2016; Sang & Chu, 2017; Zhang *et al.*, 2017.
Peanut milk	Niacin Vitamin E Arginine	• Prevents heart strokes • Effective for digestion, Skin • Greater metabolic activity	Refrigerated condition (4 ^{0}C): 30 days	Sethi *et al.*, 2016; Arya *et al.*, 2016; Fleischer *et al.*, 2019; Zaaboul *et al.*, 2019.
Rice milk	α-tocopherol β-sitosterol γ- oryzanol Thiamine Niacin Pyridoxine	• Lowers hypertension and cholesterol • Best choice for allergy people • Anti-inflammatory	Refrigerated condition (4 ^{0}C): 12 days	Sethi *et al.*, 2016; Lau & Latif, 2019; Amini *et al.*, 2019.
Soy milk	Daidzein Genistein Glycitein	• Reduces blood pressure level • Greater bone density • Lower rate of fracture • Hypolipidemic effects • Prevent chronic diseases • Effective against Osteoporosis	Ambient condition: 90 days Refrigerated condition (4 ^{0}C): 170 days	Marazza *et al.*, 2012; do Amaral Santos *et al.*, 2014; Sanjukta *et al.*, 2015; Sidhu & Singh, 2016; Dai *et al.*, 2017; Singh & Vij, 2018; Katz, 2018.

(Source: Paul *et al.*, 2019)

VII. MEAT ANALOGUES

To be formulated as meat analogues, the protein sources must have functions such as water and oil holding capabilities, solubility, emulsification, foaming, gelation characteristics, *etc*. The meat's fibrous structure and muscle texture are initially simulated by protein texturization, where the globular plant proteins are converted from their original form to linear form. Protein hydration is frequently followed by shear and heat processing, which regulates pressure, pH, moisture content, *etc*. Disruption of the initial disulphide bonds and non-covalent contacts (such as hydrogen bonds, ionic bonds, and hydrophobic bonds) of the proteins causes denaturation and considerable unfolding of the protein molecules (Vatansever *et al.*, 2020). The polypeptide chains are further oriented by shearing as they stretch in the force field's direction. New covalent and non-covalent connections between polypeptides are formed during cooling, resulting in fibrous layered structures (Samard *et al.*, 2019). It is now possible to manufacture the fibrous system of meat replacements using top-down (extrusion, shear cell, and freeze structuring) or bottom-up (spinning) methods (Dekkers *et al.*, 2018).

Soya protein concentrates and isolates are one of the most widely used protein sources for preparing meat analogues because of their functional properties like water-holding, fat-absorbing, gelling, and emulsifying capacities. Another commonly used protein for meat analogue is wheat gluten. The components like gliadin and glutenin are extracted from wheat by washing the wheat dough until the starch and bran have been rinsed off, leaving a chewy mass. It has the inherent ability to generate thin protein films upon elongation, which may be easily converted into fibrous proteinaceous materials. The molecular characteristics and subsequent mesoscopic behavior lead to a meat-like texture (Don *et al.*, 2003).

Similarly, hordein, glutelin (primary proteins in barley endosperm) and, albumin, globulin (main cytoplasmic proteins in barley bran and germ) provide the characteristic texture to the meat analogues prepared from barley. Glycinin and vicilin, which have excellent emulsion capacity and foaming stability, are two essential pea proteins appropriate for making meat analogues (Sun *et al.*, 2021). Pea protein has a lower overall gelling ability than soy protein, which leads to less elastic and softer end products (Sun *et al.*, 2021).

Plant-based meat analogues can be produced by the technologies like extrusion, simple shear flow, and spinning (Manski *et al.*, 2007). Based on phase separation inside the material, these processes cause the development of an internal structural alignment (Tolstoguzov, 2006). After structuring, the structure is solidified by heating/cooking, cooling, drying, or coagulation. The extrusion technique is the most cost-effective since food quality and production remain consistent throughout food processing. It is simple to use, clean, saves water and energy, and can handle various raw materials (Maurya and Said, 2014). Shear cell technology is used mainly to prepare plant-based meat analogues by combining heat and shear. Plant proteins were created with layered fibrous structures that mimicked the texture and mouthfeel of animal-based meat steak. This technique benefits extrusion since the deformation inside the device is highly defined and constant during production. This method develops meat substitutes that are more substantial and softer textured. Spinning technology is a sophisticated method for producing thin fibers using high-speed spinning to make mimicked meat from concentrated plant protein. However, it is a sensitive and expensive procedure involving a high proportion of acid/alkaline solvents and water, resulting in massive waste. Various spinning technologies are wet spinning, electrospinning, *etc.* In recent years, Three-Dimensional (3D) printing has emerged as one of the most innovative and adaptable technological developments. In 3D printing, the muscle-like matrix is usually recreated by mixing micro-extruding filaments derived from plant-based paste (Ismail *et al.*, 2020). Usually, Auto Computer-Aided Design (AutoCAD), a modeling program, is used to arrange this plant-based paste in the 3D printer matrix.

In comparison, freeze structuring (or freeze alignment) is a technique for creating new structures by utilizing the isotropic structure of well-mixed frozen solutions (Dekkers *et al.*, 2018). The frozen protein emulsion produces a parallel-oriented sheet-like protein product with porous and fibrous microstructures (Yuliarti *et al.*, 2021). The primary disadvantage is having to monitor and adjust different freezing conditions continuously. Various commonly used meat analogues are available in the market (Table 3).

Table 3: Commonly used meat analogues products

Meat analogues	Products
Plant-based meat analogues	
1. Coarse ground-meat analogues	Burgers, Sausages, Batter/breaded nuggets, Meatballs, Pizza toppings
2. Emulsified meat analogues	Deli meats, Frankfurters, Spreads
3. Loose fill	Tack fillings, Chili mixes, Sloppy Joe
Fermented meat alternatives	Tofu, Tempeh, Seitan, *Yobu*, Fibres, *Risofu*, *Remis Algen*

VIII. PLANT-BASED PROTEIN FROM INDUSTRIAL BY-PRODUCTS

Following oil extraction from the oil seeds or fruits, the oil processing industry produces substantial volumes of industrial by-products such as press cakes/oil meals. These by-products often contain 15 to 50 percent or more protein, making them good sources of high-quality proteins (Pojic *et al.*, 2018). The quality and protein content of oil meal/press cake is influenced by the pre-treatment processes (storage conditions, dehulling). Protein aggregation is improved, and carbohydrate-fiber bonding is tightened when defatted meals are heated to eliminate the solvent. This improves the technical properties of emulsification, foaming, solubility, and protein extraction from oil cake meals.

Dietary fiber and rice bran proteins (12–20 %) provide a high nutritional value, well-balanced amino acid profile, and health advantages such as hypoallergenic, anti-cancer, and hypocholesterolemic properties (Pojic *et al.*, 2018). Wheat bran has a protein content of 13–18 percent and has the potential to be employed in the synthesis of high-quality free amino acids, bioactive peptides, and aminobutyric acid (GABA) (Pojic *et al.*, 2018). Defatted wheat germ can also extract bioactive peptides since it has a well-balanced amino acid profile (methionine, lysine, and threonine). In addition, the processing of soybeans to make soy milk and tofu results in soy pulp and *Okara*, both of which have high residual protein levels between 25 and 33 percent. The protein contents of banana peels, muskmelon peels, watermelon peels, citrus pulp, apple pomace, and grape pomace are 8.1, 9.5, 7.9, 10.5, 7.7, and 3.8 percent, respectively. Similarly, the by-products of vegetable processing industries contain ample bioactive compounds, such as proteins, peptides, polyphenols, glycoalkaloids, carotenoids, dietary fiber, *etc.* (Wadhwa and Bakshi, 2013).

IX. EDIBLE FILMS FROM PLANT-BASED COATINGS

Edible films can be produced with lipid, carbohydrate, and protein components (Parris *et al.*, 1995); however, protein-based films exhibit superior gas barrier properties compared to those formed from lipids and polysaccharides. Edible films have been prepared from maize zein, wheat gluten, soy, cottonseed, pea, and sunflower proteins. Solutions for protein-based films and coatings are made using protein, plasticizer, and solvent-based mixtures. The features of the final film are influenced by the inherent properties of the film or coating components as well as external processing conditions. The amino acid composition, crystallinity (both of the protein and the plasticizer), hydrophobicity/hydrophilicity, surface charge, molecular size, and three-dimensional structure of proteins are some examples of the intrinsic features of proteins. Extrinsic factors include process temperature, drying conditions, pH, ionic strength, salt type, relative humidity during processing, storage, shear, and pressure.

Zein edible films cast from alcohol solutions are insoluble in water but soluble in ethanol. As a result, they have lower water vapor permeability than most other protein films made from agricultural sources and are glossy, robust, scuff resistant, and greaseproof (Shukla and Cheryan, 2001). Zein films are a relatively sound water vapor barrier. However, plasticizers are needed to make them more flexible due to their great fragility. Typically, cast film-forming solutions are dried in thin layers before being used to create soy protein films. These films are transparent and malleable when plasticized but have poor moisture barriers. Usually, thin layers of cast film-forming solutions are dried to create wheat gluten protein films or extruded (Shukla and Cheryan, 2001). These films' barrier and mechanical characteristics are significantly influenced by the production conditions, the inclusion of plasticizers, lipids, and other cross-linking agents, as well as environmental factors like temperature and relative humidity. Hot water soaking, grinding, and milk extraction are required steps in producing cottonseed films. Oilseed milk forms a layer on its surface when it is heated. As a result, these films are less durable than other protein- and synthetic-based films. Unfortunately, they are very fragile and need plasticizers to prevent breaking. Other protein films with restricted availability include those made from winged beans, peanuts, rice, peas, pistachios, lupin, grain sorghum, and cucumber pickle brine.

X. FERMENTED PRODUCTS AND BEVERAGES FROM PLANT-BASED PROTEINS

In spontaneous (natural) fermentation of the pulses, various microbiota, including lactic acid bacteria, a few fungal species, and yeasts, are used, which could result in inconsistent variations in product quality. In addition, a similar fermentation microbiota mix may encourage the development of potential infections and toxins. Different traditional plant-based beverages can be found all over the world. These include tiger nut milk, also known as horchata (Cortes *et al.*, 2005), rice, malt, and sugar-based fermented beverages, also known as *Sikhye* and *Amazake* (Jeske *et al.*, 2018), fermented sorghum or fermented millet - malt-based drink, also known as *Bushera*, *Boza*. Foods made of plant proteins often have low organoleptic acceptability. However, processing techniques like fermentation boost the nutritional value of fermented plant protein-based foods and their sensory acceptability and palatability (Leroy and De Vuyst, 2004).

In India's northern states, the fermented milk beverage *Rabadi* is very well-liked (Hussain *et al.*, 2014). The product is typically prepared from under-utilized grains, including millets and barley. The process involves mixing the grains' flour with buttermilk, followed by a 4 to 6 hours fermenting process, carried out outdoors. Before ingestion, the recipe is diluted with water, salted, boiled, and cooled. While processing *Rabadi*, cereals flour and buttermilk are combined, making the final product more nourishing, appetizing, and digestible for the consumer (Gupta and Nagar, 2014). A product called *Rabadi* has been reported to have a 30 percent reduction in phytic acid level after being fermented for about 9 hours with buttermilk (Dhankher and Chauhan, 1987).

Dhokla, typical breakfast food in India, is prepared with steamed, fermented legumes and cereal flour. Typically, it is prepared with chickpea flour and wheat semolina or soaking rice and chickpea splits, crushing the soaked grains separately, creating a mixed batter, allowing the batter to ferment overnight spontaneously, and steaming the completed result. However, modern recipes for Dhokla and Idli are identical (Sharma *et al.*, 2018). The main bacteria involved in the fermentation of chick pea-rice batter are *Lactobacillus fermentum*, *L. mesenteroides*, *Pichia silvicola*, *Streptococcus faecalis, Torulopsis pullulans,* and *T. candida*. Lactic acid bacteria are responsible for developing the distinctive *Dhokla* flavor, while yeast is responsible for batter volume, cake sponginess, and a high quantity of folic acid (Ray *et al.*, 2016).

Idli is a traditional fermented Indian breakfast dish prepared with pulses and grains. The final product is made by steaming a fermented composite batter made of rice and black gram. *Idli's* nutritional makeup reveals that it is a good source of protein and vitamins, particularly the B-vitamins. Therefore, *Idli* is a popular option to treat protein and energy deficiencies because it has a higher nutritional profile than unfermented rice and black gram.

Boza is a traditional Turkish non-alcoholic drink created from the fermentation of wheat, semolina, millet, corn, or rice with lactic acid bacteria and yeast. Boiling, cooling, filtering, adding sugar or another sweetener, and fermentation are the five main processes that summarise the boza production process (Arici and Daglioglu, 2002).

Ogi, a fermented cereal gruel made from corn, sorghum, and millet, is one of the most popular breakfast options and a crucial weaning food in West Africa (Amusa *et al.*, 2005). Sorghum and millet are typically employed as the substrate for fermentation in the creation of *Ogi*. First, it is usually made by steeping grains in plastic, enameled, or earthenware containers for 1 to 3 days to allow them to ferment. Then, *Ogi* slurry is created by wet milling and sieving fermented grains (Iwasaki *et al.*, 1991). Fermentation of cereals during *Ogi* processing releases phosphorous-bound phytate and improves lysine, tryptophan, niacin, and riboflavin contents.

Pozol is a nutritious dish made from fermented corn consumed daily by Indian and Mestizo tribes in South-Eastern Mexico (Perez-Armendariz and Cardoso-Ugarte, 2020). *Pozol* is made according to Indian and African customs by boiling corn kernels in lime water. Then, the dehulled drained seeds are ground for preparing a coarse dough, from which balls with a diameter of 5-8 cm are formed. For 1 to 5 days, dough balls are stored at room temperature after being wrapped in banana leaves. Southern Mexico also consumes modified varieties of *Pozol* made by adding seasoning components, roasted and ground mamey seeds, fermented cacao, and pataxte seeds, even though nixtamalized corn-derived *Pozol* is a typical recipe.

Injera is an ethnic traditional fermented meal (Neela and Fanta, 2020). Although teff is the primary grain used to make *Ethiopian Injera*, it can also be prepared from sorghum, finger millet, barley, and corn. Teff flour, water, and starter culture make *Ethiopian Injera* similar to a pancake. The dehulling of the grains, either manually or mechanically, grinding, creation of the dough and starter culture, and fermentation for two to three days are all steps in the preparation of *Injera*. Finally, a thick batter made of fermented dough is put onto an oiled pan and steam-steamed for two to three minutes under a tight-fitting lid (Parker *et al.*, 1989).

Pulse fermentation is dominated by lactic acid bacterial cultures, which lower the pH of the substrates to prevent the growth of pathogens and other competing microbiota. The fermentation of pulses improves the texture, nutritional value, and sensory qualities. Pulses can be fermented to produce bioactive peptides and hydrolysates with multiple uses, including antioxidant, antibacterial, anti-proliferative, and angiotensin-converting enzyme activity (Zambrowicz *et al.*, 2012). Chickpea fermentation has boosted natural protein and essential amino acid concentration. It also enhanced functional properties like digestibility, emulsification, lipids, and water absorption (Xiao *et al.*, 2015).

Due to their comparatively high protein levels and lower allergenicity concerns compared to plant-based yogurts of soy and coconut origin, the market for yogurts made from pulses is expanding rapidly (Boeck *et al.,* 2021). It has been claimed that roasting cowpea and mung beans before dehulling and soaking results in yogurt with fewer beany flavors (Rao *et al.*, 1988). Lupin seeds were soaked in a 0.5 percent sodium bicarbonate solution that was boiling to increase the acceptability of lupin yogurts. By fermenting leguminous flours with strains of bacteria (*L. rhamnosus* and *L. plantarum*) that produce heteropolysaccharides. Yogurt made from pulses improves gel structure and has a lower chance of creating odorous substances (Li *et al.*, 2014). Adding lentil flour to regular yogurt can enhance the product's nutritional, textural, and storage stability (Sameen *et al.*, 2019). Recently, a yogurt-like beverage made from cow pea extracts with characteristics similar to traditional yogurt has been produced (Aguilar-Raymundo and Velez-Ruiz, 2019). The product was also rated higher than milk yogurt based on its functional advantages. According to Li *et al.* (2016), fermented chickpea milk containing a high amount of GABA (Gamma-aminobutyric acid) has a neuroprotective effect, making it a healthier alternative to natural yogurt.

Lactobacillus strains, including *L. delbrueckii, L. plantarum, L. acidophilus,* and *L. casei*, are used to make soy yogurt, commonly known as *Sogurt*. Compared to yogurt, *Sogurt* had previously been described as having a beany scent, an overwhelming flavor, and a slightly gritty texture. Later research, however, revealed that using mixed cultures throughout the fermenting process could improve the *Sogurt's* sensory qualities. For example, it was discovered that combining Bifidobacterium breve with *S. thermophilus* and *L. acidophilus* can hide unpleasant sensory effects in yogurt grown with Bifidobacterium breve alone (Chang *et al.*, 2010).

Chinese origin *Sufu* or *Furu* is a fermented delicacy made from soybeans that resemble cheese and has a creamy smoothness that makes pairing it with breakfast cereals simple. The *Sufu* production process incorporates solid-state fermentation of soybean curd, or tofu, followed by aging in brine made of salt and alcohol. It has been found that the necessary amino acid patterns in *Sufu* (red and white) are equivalent to those in cow's milk and eggs.

Due to their exceptional nutritional and health-promoting qualities, almonds are one of the most popular fruit nuts in many food products. For people who are lactose intolerant or allergic to cow milk, almond milk that has been fermented with *Lactobacillus reuteri* and *Streptococcus thermophilus* are being considered (Bernat *et al.*, 2015a; Bernat *et al*., 2015b). *S. thermophilus* and *L. reuteri* were added to almond milk during fermentation, adding a variety of health benefits without causing apparent sensory alterations (Bernat *et al.*, 2015a). According to a different study by Kannan *et al.* (2021), fermented almond tea is more effective than fermented almond milk in preventing diabetes.

Defatted pumpkin flour was found to possess 55.4 percent protein according to the ranges of protein products (Lazos, 1986); hence it can be categorized as a protein flour. Additionally, it has been proposed that the seed kernels of watermelons, pumpkins, and paprika are excellent sources of high-quality protein that contain reasonable levels of lysine and other crucial amino acids (El-Adawy and Taha, 2001). Furthermore, the fermentation of melon seeds reduces the number of inherent toxicants, such as phytates, oxalates, and saponins, while simultaneously enhancing the seeds' ability to supply nutrients (Ibukun and Anyasi, 2013).

Ogiri, a significant Nigerian condiment, is made by fermenting watermelon seeds. The product is often caused by boiling the de-husked watermelon seeds until they are tender. Mushy melon seeds are wrapped in banana leaves and recooked for two to three hours. The seeds' water and oil contents are removed from the seed pulp that has been wrapped. The wrapped pulp is put into earthenware airtight jars, where it ferments for five days with little oxygen exposure. Before being used as a condiment, the fermented mash is smoked for two hours over charcoal heat. The dried mash is then powdered and used later as a condiment (Odunfa, 1981). *Proteus*, *Pediococcus*, *Klebsiella*, *Bacillus*, and *Escherichia* are among the microorganisms that are regularly isolated at different phases of *Ogiri* fermentation. Due to their useful qualities as a thickener, source of protein, and flavoring element, *Ogiri egusi* is widely used in soup preparation (Abaelu *et al.*, 1990).

XI. OTHER PRODUCTS FROM PLANT-BASED PROTEIN: ENRICHED AND FORTIFICATION OF FOOD

Foods' softness, structural stability, lubricity, and mouthfeel are all influenced by fat. The addition of protein components to the formulations can also provide these effects. Due to its better emulsifying and foaming abilities, rice bran protein (RBP) has successfully substituted fat in manufacturing low-fat franks (Bloukas and Paneras, 1996).

Soy protein isolates and defatted soy flour are frequently used in baked goods instead of milk powder due to their nutritional, practical, and cost-effective qualities. It has been observed that the absorption, crumb body, crust color, elasticity, freshness, and toasting properties of bread are all enhanced by the addition of 1-3 percent defatted soy flour. Protein isolates derived from pea, chickpea, and lentils that are 3 percent can be used to make bread with an appropriate loaf volume and hardness (Aider *et al.*, 2012). Doughnuts are a deep-fried culinary product made of white flour that absorbs much fat during cooking. However, soy protein in doughnuts causes decreased fat absorption, possibly due to heat protein denaturation that prevents fat absorption. The doughs made with soya isolates and concentrates had a homogeneous texture and were more flexible, smooth, and less sticky.

Additionally, the completed bakery products had improved grain size, symmetry, texture, and crust color (Golbitz, 1995). As a result, they stayed fresher for longer. Products, including bread, doughnuts, cookies, muffins, tortillas, and cakes, are regularly prepared using pre-cooked or unflavoured pea flour. As pea flour is high in the amino acid lysine, the addition's goal is to raise the protein level of everyday dishes. However, in foods with higher inclusion rates, pre-cooked pea flour did not transmit the usual pea flavor or taste (Tulbek *et al.*, 2017).

Lupin's higher fiber and protein content make it a suitable candidate for use in a wide range of food products. It not only has a better flavor than beans, peas, and lentils but also contains a better amino acid profile, making it a common ingredient in various savory and sweet meals. The lupin hulls are removed and processed into fiber-rich flour that can be used to improve bread and other baking foods. Lupin Protein Isolates (LPIs) can be used to replace animal protein since they have greater functional characteristics. The roasted lupin flour-based bread improver is used in cookies, waffles, specialty bread, and cakes to add yellow color, texture, structure, and other functional qualities, including water-binding and emulsification to what eggs do. When added to a fortified dough, the water-binding capacity of lupin aids in maintaining the bread quality (Kohajdova *et al.*, 2011). Lupin was also used to make a cheese substitute that involves soaking seeds in water for seven days before being boiled for around two hours. The seeds were peeled, chopped, and ground into a smooth paste, then stored in the freezer until needed.

For military and emergency rations, as well as public sector nutrition programs, pasta products like Spaghetti and macaroni are frequently fortified with pre-mixed vitamins and minerals, defatted soy flour, whole wheat flour, and soy protein isolates (SPI) up to 15 percent level (Tsen *et al.*, 1975). Pea flour and pea proteins are also essential components in durum wheat-based pasta, Chinese vermicelli noodles, and soy protein additives.

Soy sauce, a popular liquid condiment produced from soybeans and wheat, is a trademark of East Asian countries (Kobayashi *et al.*, 2004). Traditional Asian soy sauce is a light brown to dark liquid with a strong umami flavor (Yokotsuka, 1986). More than 90 percent of soy sauce is of the *Koikuchi* variety, a concoction made of fermented sauce, hydrolysate of defatted soybeans, and toasted wheat in equal amounts (Yokotsuka, 1961).

Lentils, along with beans and peas, are a staple ingredient in many different South Asian cuisines (Thomas-Patel, 2014). For example, in India, rice-lentil batters are typically eaten for breakfast, lunch, or dinner. These nutrient-dense mixtures offer sufficient levels of protein (Decker, 2018). To provide the requirement for protein and minerals in gluten-free diets, dehulled split lentils and lentil flour are widely employed. Split lentils can also be added to salads and served as a main meal or side dish. In addition, this lentil flour has many uses in purees, soups, and stews.

Additionally, it can be used as a meat extender and infant food, and it can be used with cereals to make cakes and bread (Williams and Singh, 1988). Other potential protein uses for lentils include aquaculture feed, pet food, TVP, meat extenders, complementary infant foods, nutrition and sports bars, and complementary infant foods with protein. Edible films made from lentil proteins that are equivalent to other edible protein films have been created in terms of optical, mechanical, and barrier properties (Bamdad *et al.*, 2006). Similar results were obtained with microcapsules made from lentil protein isolates to deliver flaxseed oil through the gastrointestinal tract (Karaca *et al.*, 2013).

Rice bran proteins (RBP) are an ideal component for baby food due to their distinct nutritional and hypoallergenic qualities (Helm and Burks, 1996). RBP has been used as a milk substitute in infant formulae (Landers and Hamaker, 1994). These can also replace cereals, explicitly made for infant food formulation to counter allergies. RBPs are commonly utilized in product development since they are inexpensive and widely accessible. Long employed as favor promoters, protein hydrolysates are highly effective when combined with glutamic acid and its salts, such as monosodium glutamate (MSG). However, because of health concerns, MSG has been outlawed in several nations. The RBPs have the potential to create favorable conditions or favorable conditions enhancers.

In addition to their use in ordinary meals, plant proteins have several other roles in the food system. Like other proteins, RBPs create stable color conjugates and serve as carriers for the uniform distribution of colorants in food systems. For example, freshly stabilized and parboiled rice bran is a coarse powder with a cream color, no flavor, and no odor. These qualities enable its use as a bulking and thickening agent in various compositions. From rice bran, an emulsifier with outstanding surface activity and potential industrial uses in food processing has been created (Yun and Hong, 2007). Products containing rice protein have been added to gels, puddings, ice creams, snack foods, edible films, and breakfast cereal (Adebiyi *et al.,* 2008; Chrastil, 1992). In addition, RBP concentrates have been used in drinks, soups, pastries, desserts, gravies, meat products, sauces, and other savory applications. Like hydrolysates from other protein sources, RBP hydrolysates can be used as a functional ingredient in meals like coffee whiteners, confections, beverages, and juices, as well as a nutritional supplement (Fabian and Ju, 2011).

XII. NUTRITIONAL ATTRIBUTES AND BIOAVAILABILITY OF PLANT-BASED PROTEIN

Protein, as a macronutrient essential, constitutes human tissues. Proteins are the primary constituents of all enzymes. Proteins are necessary for metabolic processes, development, and maintenance, operate as hormones and chemical messengers, regulate physiological pH and the immune system, and serve as molecular repositories and transporters. The recommended dietary allowance states that individuals should consume 0.8 grams of protein per kilogram of body weight per day while engaging in just moderate physical activity. For a healthy adult, consuming 2 grams of protein per kilogram weight per day is safe. However, 3.5 grams of protein per kilogram weight per day is the top tolerated limit, resulting in vascular, digestive, and reproductive problems (Wu, 2016). Different plant protein sources contain various amino acids. Some of them are deficient in essential amino acids, *e.g.*, some cereals are low in lysine, tryptophan, and threonine content; vegetables and legumes lack sulphur-containing amino acids (methionine and cysteine). The amino acid availability depends on the protein sources and processing conditions. The amino acids can be classified into three groups based on their relative or absolute rates of protein synthesis in vivo: (a) indispensables (valine, tryptophan, threonine, phenylalanine, methionine, lysine, leucine, isoleucine, and histidine); (b) conditionally indispensables (tyrosine, cysteine, and arginine); and (c) dispensable (serine (Volpi *et al.*, 2003). So, various nutritional experts suggested consuming a combination of plant-based protein to fulfill the demand for amino acids. Consumption of minimum protein quantity is essential, but protein quality is also a crucial factor during the consumption of protein in terms of different health aspects (Millward *et al.*, 2008).

Protein quality is based on essential amino acid composition that can be easily digestible and utilized for protein synthesis (Mattila *et al.*, 2018). Other factors defining the protein quality are protein digestibility-corrected amino acid score (PDCAAS), biological value (BV), and net protein utilization (NPU). The amino acid profile of a specific protein determines its metabolic rate. The PDCAAS and digestible indispensable amino acid score (DIAAS) method is used for the quality evaluation of protein and is recommended by Food and Agriculture Organization in 2013 (Malik *et al.*, 2017). BV measures the amount of protein assimilated into the body from food. The NPU is the ratio of amino acid mass converted to proteins and the mass of amino acids supplied. The factors affecting the nutritional quality of plant-based proteins are crop variety, crop maturity, soil condition, use of fertilizer and pesticides, post-harvest handling, storage, and climatic condition.

Plant-based proteins have several health benefits over animal proteins as they provide plenty of nutrients, protection against heart disease, protection against cancer, protection against strokes, and protection against type 2 diabetes (Luna-Vital *et al.*, 2015; Luna-Vital *et al.*, 2018). In addition, plant-based protein sources are lower in iron, saturated fat, and hormones, reducing the risk of heart disease, and a higher concentration of phytochemicals prevents cancer. Also, another significant advantage of being vegetarian is the reduced problem of being overweight (Langyan *et al.*, 2021).

XIII. ANTINUTRITIONAL FACTOR IN PLANT-BASED PROTEIN

Most plant-based protein contains antinutrients that plants naturally produce. Some major antinutritional factors are protease inhibitors, lecithin, phytoestrogens, saponins, goitrogenic factors, rachitogenic factors, phytic acids, mycotoxins, allergens, and lipoxidases. This antinutritional factor then interferes with nutrient absorption, digestion, and utilization in food products (Popova and Mihaylova, 2019).

Raw grains and legumes, mainly soybean, contain protease inhibitors. They lead to poor food consumption, pancreatic hypertrophy, and growth suppression (Adeyemo and Onilude, 2015; Kadam *et al.*, 1990). Lecithin is widely distributed in plant proteins or glycoproteins of non-immune origin in plants, including wheat, beans, quinoa, peas, almonds, *etc*. They can go past the human immune system and cause illnesses like Crohn's, coeliac, and colitis (Yasuoka *et al*., 2003). The leaky gut syndrome is caused by intestinal permeability and perforations in the gut wall caused by excessive lectin ingestion (Popova and Mihaylova, 2019). In addition to causing autoimmune illnesses by misrepresenting immune system coding and promoting the proliferation of specific white blood cells, lecithin increases insulin release by the pancreas (Karpova, 2016; Fahmi *et al*., 2017). Phytase is mainly found in seeds, grains, nuts, and legumes. In the form of phytin or phytate, salt stores phosphorus as phytic acid in its husks. Mineral bioavailability, protein and carbohydrate solubility, functioning, and digestibility are all reduced by phytases (Salunkhe *et al*., 1990). Similarly, saponins are bitter-tasting substances in foods, including quinoa, amaranth, bucket wheat, teff, soybeans, chickpeas, and beans. They interfere with the digestion and metabolism of nutrients, bind to minerals like zinc, and influence nutritional absorption (Fan *et al*., 2013). They may also lead to problems with protein digestion, vitamin and mineral absorption, the emergence of a leaky gut, and hypoglycemia (El Barky *et al*., 2017; Johnson *et al*., 1986).

Most side effects of the antinutritional factor of plant-based protein are seen when consumed unprocessed. The antinutrients present in the protein sources can be minimized or removed using techniques like soaking, cooking, fermentation, radiation, germination, genomic technologies, and chemical treatments (Bains *et al*., 2014; Gupta *et al*., 2015). The combination of these methods has been observed to be very effective.

XIV. PLANT-BASED PROTEIN MARKET AVAILABILITY

Consumer awareness has increased after the COVID-19 pandemic, making them conscious of the food they eat. Increased awareness of health and organic food alternatives that are natural and environment-friendly for better immunity systems has fuelled the demand for plant-based proteins. During the pandemic, the sale of these plant-based proteins has increased manifold. Sales of soy, pea, and wheat proteins have increased due to the expansion of online channels and the eCommerce sector. To meet customer demand, businesses in the plant-based protein industry are creating cutting-edge goods. Manufacturers are expanding the selection of advanced items they provide in various formats. Some of the most well-liked goods among customers include supplements and nutritious powders. Manufacturers in the market for plant-based proteins are looking at chances to improve product quality and nutritional benefits. Different sources of plant-based proteins include soy, wheat, peas, and others. During the projected 2021–2031, the pea protein sector shows considerable market growth, with a CAGR of 6.9 percent (Anonymous, 2022b).

According to a recent survey, the South and East Asian regions have witnessed the highest growth rate of 6.8 percent and 6.3 percent, respectively. Among various products, soya proteins hold the largest share in the global market, accounting for the market value of around 64.4 percent, worth 8,433.40 million US Dollars (Anonymous 2022b). The current market size of plant-based proteins is 11.3 billion US Dollars. The market forecast value in 2032 is estimated to be 22.5 billion US Dollars with a growth rate (CAGR) of 7.2 percent (Anonymous 2022c). Table 3 and Table 4 present the segmentation and key players in the plant-based protein market, respectively.

Table 3: Segmentation in the Plant-Based Protein Market

Product Type	Form	Application	Region
Soy Protein	Isolate	Supplements & Nutritional	North America
Wheat Protein	Concentrate	Powders	Latin America
Pea Protein	Others	Beverages	Europe
Others		Protein & Nutritional Bars	East Asia
		Bakery & Snacks	South Asia
		Breakfast Cereals	Oceania
		Meat Products	Middle East & Africa
		Dairy Products	
		Infant Nutrition	
		Animal Feed	
		Others	

Table 4: Key Players in the Plant-Based Protein Market

Key players	Country
Ag Processing Inc.	USA
AGT Food & Ingredients, Inc.	Canada
AMCO Proteins	USA
Archer Daniels Midland Company	USA
Axiom Foods Inc.	USA
Batory Foods	USA
BENEO GmbH	Germany
Bio press S.A.S.	France
Burcon Nutrascience Corporation	Canada
Cargill Incorporated	USA
CHS Inc.	USA
Corbion NV	The Netherlands
Cosucra Groupe Warcoing SA	Belgium
Crespel & Deiters GmbH & co. kg	Germany
Crown Soya Protein Group	China
Devansoy Inc.	USA
DuPont de Nemours, Inc.	USA
Fuji Oil Holdings Inc.	Japan
Glanbia plc.	Ireland
Glico Nutrition Co. Ltd.	Japan
Gushen Group Co., Ltd.	China
Imagine Meats	India
Ingredion Inc.	USA
ITC	India
Kerry Group	Ireland
Mister Veg	India
Now Foods	USA
Roquette Freres Le Romarin	France
Royal Avebe	The Netherlands
Shandong Yuwang Ecological Food Industry Co.	China
Sotexpro	France
TATA	India
The Scoular Company	USA
Wilmar International Ltd.	Singapore

XV. CONCLUSIONS

Our expanding society's need for protein-enriched food is a top worry as we emphasize eating a varied, nutritious diet. Foods with plant-based proteins are highly regarded since they offer functional and nutritional advantages. It is becoming increasingly common to replace animal protein with complete and balanced proteins of plant origin. Fermentation has lately emerged as a viable method to ensure the proper utilization of plant foods. It improves nutritional quality, nutrient digestibility and bioavailability, and consumer palatability. Although fermenting grains, pulses, legumes, nuts, tubers, and roots has a long history in many civilizations worldwide, little is known about recent developments in using fermented plant proteins to make protein-based health products and to reduce food and nutritional security. The commercial production and availability of plant protein components have created new opportunities for their use in the fortification and enrichment of conventional food products. This approach may help reduce nutrient disparities among vulnerable populations, particularly in developing and developing nations. Additionally, these value-added components can be employed to create designer cuisine using extrusion and 3-D technologies. Increased consumption of plant-based protein can reduce the prevalence and severity of non-communicable illnesses in health-conscious consumers from industrialized nations.

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