**Plant-Based Protein: A Way Forward for Nutrition Sustainability**

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**Abstract:**

In recent years, plant-based proteins are gaining much more importance due to various reasons. While, traditionally, nuts and legume crops were considered as the natural sources of plant proteins, with the advancement of extraction technologies, proteins are being derived from a wide range of cereals, vegetables, vegetable seeds, algae, and other edible seeds, which can be alternative protein sources. Besides, the anti-nutritional 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 minimise the health deterrent factors associated with plant-based proteins. Plant based proteins are not confined to the milk and meat analogues anymore; they are now constituting a part of the customised 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, in this dwindling climatic condition, availability of these plant-based proteins will pave the way for meeting of healthy body and soul requirements.

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

**I. INTRODUCTION**

The human body requires different nutrients (water, carbohydrates, protein, fat, vitamins and minerals) to perform its essential functions. A majority of these nutrients are used in providing energy, contributing to the body structure and maintaining chemical processes in the body. Among these nutrients, proteins play a vital role as they provide structural as well as functional support and 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 amino acids, which are produced inside the human body and essential amino acids, which the human body does not produce and must be fulfilled by using different protein-rich food items. These protein-rich sources can be differentiated into animal-based and plant-based. Even though a majority of essential amino acids are fulfilled from animal sources, the change in consumer preferences also led to exploring other sources of protein. 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 mind-set of consumers towards plant protein. The first major 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 diseases, *etc.*, which are life threatening and putt 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. As, the production of meat and dairy need 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 the religious and cultural beliefs and they feel animal slaughtering is sign of cruelty. Presently, many value-added products have been formulated from plant-based proteins like milk and meat analogues, fermented products and beverages, edible films, protein enriched and fortified foods, *etc.*

Animal milk is considered to be wholesome food providing macro and micronutrients, which help in the growth and maintenance of the body, but lactose intolerance is rapidly spreading across the globe, particularly among the elderly population. 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 the 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 the 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. 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 as a result of consumer demand for healthy diets, concern over rising meat prices, growth in popularity of vegetarianism, and growing consumer interest towards eating behaviours like avoiding or lowering intake of red meat. It's also intriguing to employ a different source, such 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 fibres, 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 a variety of sectors, particularly in industrialised 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 different 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 their counterparts 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 categorised 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 (expect 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, pea, beans, *etc.*), 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. Intake of animal proteins provides additional benefits of vitamin D, cobalamin, omega 3, zinc, heme-iron and menaquinone, whereas, plant proteins are associated with ascorbic acid, fibre and flavonoids, polyunsaturated fatty acids, oligosaccharides, and carbohydrates. Some studies have reported adverse health effects on the body as animal protein sources contain saturated fat and a higher level of cholesterol. 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 is a different type of plant-based proteins; some of them provide all essential amino acids required for the human body. There are various sources of plant-based proteins (Table 1).

**Table 1: Plant based proteins**

|  |  |  |  |
| --- | --- | --- | --- |
| **S. 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 grown for their edible seeds as well as oil seeds. |
| 3. | Lentils  | Around 25 % | Edible legumes high in fibre and carbohydrate content and low in fat content.  |
| 4. | Mycoprotein  | Around 11 % | A type of 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 fibre and omega-3 fatty acids.  |
| 9. | Vegetables  | 2 – 8 % | Vegetables like spinach, broccoli, asparagus, artichokes, potatoes, sweet potatoes and brussels are rich in protein.  |
| 10. | Nutritional yeast | Around 8 % | 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 fibre, 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 species of wheat. 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 methods of modification are physical, chemical, and biological (Fig 1).

The process of protein extraction or purification includes isolating and purifying one or few proteins from a complex mixture. The protein extraction techniques improve the yield and the functional and nutritional qualities of extracted protein. To increase the efficiency, proper method of extraction 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 forms of protein products containing more than 80 per cent of proteins and no dietary fibre (Sim *et al.*, 2021). These are extremely easily integrated into many food items and are very digestible. They also offer the benefits of colour, flavour, and functional qualities, which makes them a perfect component for drinks, baby foods, textured protein products, and several specialised food varieties. Plant-based protein isolates have been taken from a variety of plant sources, including pinto, navy, and 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 per cent. (Sim *et al.*, 2021). The process of making leaf protein concentration (LPC), the most popular type of plant protein, involves first pulping young leaves and then 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 important 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, *viz*., 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 employs dialysis, isoelectric, micellar precipitation, and ultrafiltration/diafiltration methods (Zhu *et al.*, 2010). The standard alkaline procedure is the conventional method for the extraction of protein, where precipitates formed by the alkaline treatment are washed to eliminate contaminants (Mondor *et al.*, 2010), followed by a purification procedure such as dialysis or ultrafiltration yields protein hydrolysate (Chittapalo *et al.*, 2009). Since alkaline treatment may result in unfavourable reactions, reduction in protein digestibility and the loss of certain amino acids, novel technologies such as pulsed electric field, ultrasound, and microwave are used to increase extraction efficiency and also 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 colour and texture mimic those of animal milk; however, its natural makeup cannot be compared to that of 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). 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. The proteolytic *Lactobacilli* strain ensures the release of peptides and amino acids during yoghurt fermentation, while *Streptococcus* supplies with 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. The presence of a variety of micro and macronutrients in grains provides the environment necessary for the development of lactic acid bacteria and improves the bioavailability of nutrients. 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). High molecular weight polysaccharides produced by lactic acid bacteria increase the substrate's viscosity, a crucial component of the texture of yoghurt and fermented beverages made from cereals.

 Plant-based milk is high in fibres, 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. 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 when 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 ENiacinStigmasterol folateβ-sitosterol | * Low calorie
* Probiotic
* Powerful antioxidant
 | Refrigerated condition (4 0C): 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 | CaffeineTheobromine | * Anti-aging
 | Ambient condition (25-37 0C): 21 daysRefrigerated condition (5-10 0C): 3 months | Neti & Azhari, 2010;Maciel *et al.*, 2017. |
| Coconut milk | Vitamin ELauric acid | * Anti-aging
* weight loss
* Boosts immune system
 | Refrigerated condition (4 0C): 30 days | Agarwal & Bosco, 2014; Sethi *et al.*,2016; Katz, 2018;Mauro & Garcia, 2019. |
| Hemp milk | Linolenic acidLinoleic acidTocopherol | * Anti-inflammatory
* Anti-thrombotic
 | Refrigerated condition (4 0C): 3 days | Teh & Birch 2014;Crescente *et al.*, 2018;Zhou *et al.*, 2018; Wang *et al.*, 2018. |
| Kidney bean | $γ$-aminobutyric acid (GABA)Dietary fibres | * Anti-oxidant
* β-glucosidase activity
 | - | Limon, 2014; Kumar *et al.*, 2013. |
| Oat milk | AvenanthramidesPhytochemicalsβ –glucan | * Decreases blood glucose level
* Hypocholesterolaemic
* Anti –pathogenic effect
 | Refrigerated condition (4 0C): 28 days | Bernat *et al.*, 2015c; Sethi *et al.,* 2016; Sang & Chu, 2017; Zhang *et al.*, 2017. |
| Peanut milk | NiacinVitamin EArginine | * Prevents heart strokes
* Effective for digestion, Skin
* Greater metabolic activity
 | Refrigerated condition (4 0C): 30 days | Sethi *et al.*, 2016; Arya *et al.*, 2016; Fleischer *et al.*, 2019; Zaaboul *et al.*, 2019. |
| Rice milk | α-tocopherolβ-sitosterol$γ$- oryzanolThiamineNiacinPyridoxine | * Lowers hypertension and cholesterol
* Best choice for allergy people
* Anti-inflammatory
 | Refrigerated condition (4 0C): 12 days | Sethi *et al.*, 2016; Lau & Latif, 2019; Amini *et al.*, 2019. |
| Soy milk | DaidzeinGenisteinGlycitein | * Reduces blood pressure level
* Greater bone density
* Lower rate of fracture
* Hypolipidemic effects
* Prevent chronic diseases
* Effective against Osteoporosis
 | Ambient condition: 90 daysRefrigerated condition (4 0C): 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 need to have functions such as water and oil holding capabilities, solubility, emulsification, foaming, gelation characteristics, *etc.* Initially, the fibrous structure and muscle texture of the meat are simulated by a process called 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 in this procedure, which involves regulating parameters like 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 structure 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 behaviour 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 primarily used for the preparation of plant-based meat analogues by combining heat and shear. Plant proteins were created with layered fibrous structures that mimicked the texture and mouth-feel of animal-based meat steak. This technique has a benefit over 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 fibres using high-speed spinning to make mimicked meat from concentrated plant protein. 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 modelling programme, 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 utilising the isotropic structure of well-mixed frozen solutions (Dekkers *et al.*, 2018). The frozen protein emulsion results in 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. There are various commonly used meat analogues available in market (Table 3).

**Table 3: Commonly used meat analogues products**

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| --- | --- |
| **Meat analogues** | **Products** |
| Plant-based meat analogues |  |
| 1. Coarse ground-meat analogues
 | Burgers, Sausages, Batter/breaded nuggets, Meatballs, Pizza toppings |
| 1. Emulsified meat analogues
 | Deli meats, Frankfurters, Spreads |
| 1. 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 the extraction of oil from the oil seeds or fruits, the oil processing industry produces substantial volumes of industrial by-products such press cakes/oil meals. These by-products often contain 15 to 50 per cent or more protein on average, making them good sources of high-quality proteins (Pojic *et al.*, 2018). The quality and protein content of oil meal/press cake are influenced by the pre-treatment processes (storage conditions, dehulling). Protein aggregation is improved and carbohydrate-fibre 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 fibre and rice bran proteins (12–20 %) provide the high nutritional value, well-balanced amino acid profile, and health advantages such hypoallergenic, anti-cancer, and hypocholesterolemic properties (Pojic *et al.*, 2018). Wheat bran has a protein content of 13–18 per cent 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 be utilised to 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 per cent. 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 per cent, respectively. Similarly, the by-products of vegetable processing industries contain ample bioactive compounds, such as proteins, peptides, polyphenols, glycoalkaloids, carotenoids, dietary fibre, *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. Examples of 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. They have lower water vapour permeability than the majority of other protein films made from agricultural sources and are glossy, robust, scuff resistant and greaseproof (Shukla and Cheryan, 2001). Zein films are a relatively good water vapour barrier. However, due to their great fragility, plasticizers are needed to make them more flexible. Typically, cast film-forming solutions are dried in thin layers before being used to create soy protein films. When plasticized, these films are transparent and malleable 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). The barrier and mechanical characteristics of these films 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 the production of cottonseed films. Oilseed milk forms a layer on its surface when it is heated. 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 the fermented plant protein-based foods as well as 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-utilised grains, including millets and barley. The process involves mixing the grains' flour with buttermilk, followed by a 4 to 6 hours fermenting process, which is 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, appetising, and digestible for the consumer (Gupta and Nagar, 2014). A product called *Rabadi* has been reported to have a 30 per cent 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. Modern recipes for *Dhokla* and *Idli*, however, are essentially 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 the development of the distinctive *Dhokla* flavour, 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 gramme. *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 can be used to 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*. It is usually made by steeping grains in plastic, enamelled, 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 kernels are ground for preparing coarse dough, from which balls with a diameter of 5-8 cm are formed. For a period of 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 nixtamalised corn-derived *Pozol* is a common 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 are used to 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 so as to prevent the growth of pathogens and other competing microbiota. The texture, nutritional value, and sensory qualities are improved by the fermentation of pulses. Pulses can be fermented to produce bioactive peptides and hydrolysates that have multiple uses, including antioxidant, antibacterial, anti-proliferative, and angiotensin-converting enzyme activity (Zambrowicz *et al.*, 2012). Chickpea fermentation has been shown to boost natural protein and essential amino acid concentration and functional properties like digestibility, emulsification, absorption of lipids, and water absorption (Xiao *et al.*, 2015).

Due to their comparatively high protein levels and lower allergenicity concerns compared to plant-based yoghurts of soy and coconut origin the market for yoghurts 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 yoghurt with fewer beany flavours (Rao *et al.*, 1988). Lupin seeds were soaked in a 0.5 per cent sodium bicarbonate solution that was boiling to increase the acceptability of lupin yoghurts. By fermenting leguminous flours with strains of bacteria that produce heteropolysaccharides, including *L. rhamnosus* and *L. plantarum*, yoghurt made from pulses improves in gel structure and has a lower chance of creating odorous substances (Li *et al.*, 2014). Adding lentil flour to regular yoghurt can enhance the product's nutritional, textural, and storage stability (Sameen *et al.*, 2019). Recently, a yoghurt-like beverage made from cow pea extracts with characteristics similar to traditional yoghurt has been produced (Aguilar-Raymundo and Velez-Ruiz, 2019). Based on its functional advantages, the product was also rated higher than milk yoghurt. 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 yoghurt.

*Lactobacillus* strains, including *L. delbrueckii, L. plantarum, L. acidophilus,* and *L. casei*, are used to make soy yoghurt, commonly known as *Sogurt*. Compared to yoghurt, *Sogurt* had previously been described as having a beany scent, an overwhelming flavour, 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 yoghurt 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 ageing 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 and are used 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 per cent protein according to the ranges of protein products (Lazos, 1986); hence it can be categorised 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 made 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 flavouring 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 been discovered to successfully substitute 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 colour, elasticity, freshness and toasting properties of bread are all enhanced by the addition of 1-3 per cent defatted soy flour. Protein isolates derived from pea, chickpea and lentils that are 3 per cent can be used to make bread that has 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 colour (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 flours. As pea flour is high in the amino acid lysine, the addition's goal is to raise the protein level of common dishes. However, in foods with higher inclusion rates, using precooked pea flour did not transmit the usual pea flavour or taste (Tulbek *et al.*, 2017).

Lupin's higher fibre and protein content make it a suitable candidate for use in a wide range of food products. It not only has a better flavour than beans, peas and lentils but also contains a better amino acid profile, making it a common ingredient in a variety of savoury and sweet meals. The lupin hulls are removed and processed into fibre-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, speciality bread and cakes to add yellow colour, texture, structure and other functional qualities, including water-binding and emulsification, similar 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 programmes, 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 per cent level (Tsen *et al.*, 1975). Pea flour and pea proteins are also utilised as a basic component in durum wheat-based pasta, noodles, and Chinese vermicelli noodles, in addition to 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 flavour (Yokotsuka, 1986). More than 90 per cent 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). 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 lentil and lentil flour are widely employed. Split lentils can also be added to salads and served as a main meal or side dish. Similar to this, lentil flour has a wide range of 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 for the delivery of 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 a common element utilised in product development since they are inexpensive and widely accessible. Long employed as favour 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 favourable conditions or favourable conditions enhancers.

In addition to their use in ordinary meals, plant proteins have several other roles in the food system. Similar to other proteins, RBPs create stable colour conjugates and serve as carriers for the uniform distribution of colourants in food systems. Rice bran that has been stabilised and parboiled is a granulated powder with a cream colour, no flavour, and no odour. These qualities enable its use as a bulking and thickening agent in a variety of 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). RBP concentrates have been used in drinks, soups, pastries, desserts, gravies, meat products, sauces, and other savoury applications. Similar to hydrolysates from other protein sources, RBP hydrolysates can be utilised 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 essential 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 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. 3.5 grams of protein per kilogram weight per day, which is the top tolerated limit, resulting in vascular, digestive, and reproductive problems (Wu, 2016). Different plant protein sources contain different amino acids. Some of them are deficient in specific 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 fulfil the required demand for amino acids. Consumption of minimum protein quantity is important but protein quality is also a crucial factor during the consumption of protein in terms of different health aspects (Millward *et al.*, 2008).

The quality of protein is based on essential amino acid composition that can be easily digestible and utilised 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 can be defined as 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.

There are several health benefits of plant-based proteins over animal protein as it provides 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). Plant-based protein sources are lower in iron, saturated fat and hormones which reduces the risk of heart disease, and a higher concentration of phytochemicals prevents cancer. Also, another major advantage of being vegetarian is the problem of being overweight is reduced (Langyan *et al.*, 2021).

**XIII. ANTINUTRITIONAL FACTOR IN PLANT-BASED PROTEIN**

 Most plant-based protein contains antinutrients which are naturally produced by plants. Some of the major anti-nutritional factors present are protease inhibitors, lecithin, phytoestrogens, saponins, goitrogenic factors, rachitogenic factors, phytic acids, mycotoxins, allergens and lipoxidases. This antinutritional factor then interferes with the absorption, digestion and utilisation of nutrients present in food products (Popova and Mihaylova, 2019).

Raw grains and legumes, particularly 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 have the ability to go past the human immune system and cause illnesses including Crohn's disease, coeliac disease, and colitis (Yasuoka *et al*., 2003). 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 certain white blood cells, lecithin increases the release of insulin by the pancreas (Karpova, 2016; Fahmi *et al*., 2017). Phytase is mostly found in seeds, grains, nuts, and legumes. In the form of phytin or phytate salt, they store phosphorus as phytic acid in their husks. Mineral bioavailability, protein and carbohydrate solubility, functioning, and digestibility are all reduced by phytoses (Salunkhe *et al*., 1990). Similarly, saponins are bitter-tasting substances found in foods including quinoa, amaranth, bucket wheat, teff, soybeans, chickpeas, and beans. They interfere with the digestion and metabolism of nutrients as well as 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).

The majority of side effects of the antinutritional factor of plant-based protein are seen when it is 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 cutting-edge 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 nutritive benefits. Different sources of plant-based proteins include soy, wheat, peas, and others. During the projected period of 2021–2031, the pea protein sector is showing considerable market growth, with a CAGR of 6.9 per cent (Anonymous, 2022b).

According to a recent survey, the South and East Asian regions have witnessed the highest growth rate of 6.8 per cent and 6.3 per cent, respectively. Among various products, soya proteins hold the largest share in the global market, accounting for the market value of around 64.4 per cent, worth 8,433.40 million US Dollars (Anonymous 2022b). The current market size of plant-based proteins is 11.3 billion US Dollars, and the market forecast value in 2032 is estimated to be 22.5 billion US Dollars with a growth rate (CAGR) of 7.2 per cent (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 ProteinWheat ProteinPea ProteinOthers | IsolateConcentrateOthers | Supplements & Nutritional PowdersBeveragesProtein & Nutritional BarsBakery & SnacksBreakfast CerealsMeat ProductsDairy ProductsInfant NutritionAnimal FeedOthers | North AmericaLatin AmericaEuropeEast AsiaSouth AsiaOceaniaMiddle East & Africa |

**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 |
| Biopress 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 place more of an emphasis on eating a varied, nutritious diet. Foods with plant-based proteins are highly regarded since they offer both functional and nutritional advantages. It is becoming more and more common to replace animal protein with full and balanced proteins of plant origin. By enhancing nutritional quality, nutrient digestibility and bioavailability, and consumer palatability, fermentation has recently come to light as a promising technique to ensure appropriate usage of foods of plant origin. Although fermenting grains, pulses, legumes, nuts, tubers, and roots has a long history in many civilizations throughout the world, 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 the most vulnerable populations, particularly in developing and poor 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 industrialised nations.

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