



Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.1.075>

THE PLANT ADVANTAGE: UNLOCKING THE SECRETS OF PLANT-BASED PROTEINS

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(Date of Receiving-05-10-2023; Date of Acceptance-13-02-2024)

ABSTRACT

Proteins are an essential macronutrient that has been trending positively in the minds of consumers, with demand increasing for both plant and animal protein sources. Plant proteins are preferable as animal proteins can have negative health consequences on humans. Plant-based proteins are more economical and consequently greater value for money. Nutritionally speaking, the proper combination of proteins from various plant sources can provide enough necessary amino acids to meet the demands of human health. The need to promote the shift to plant-based diets with lower meat intake is becoming more widely recognised as a means of reducing the negative environmental effects of the food system as well as enhancing human and animal welfare. The preference of consumers for plant-based protein sources over animal food sources due to their substantial health advantages, environmentally friendly, sustainable production methods and morality. The manufacture of meat and fish analogues uses a variety of methods, such as extrusion, shear cell technology, spinning, frizzling, etc. Plant-based proteins are widely available and have a wide range of industrial uses. For example, they may be employed as bioactive peptides or as a dairy alternative or plant-based meat substitute. Therefore, the food business must adjust increasingly cutting-edge artificial meat technology to the demands of consumers. Doing so might significantly contribute to improving the ecological situation and eradicating dietary deficiencies in humans.

Key words : Macronutrient, Extrusion, Shear cell technology, Spinning, Freezing.

Introduction

As the population grows, the demand for food increases. In such a condition, meeting nutritional needs is not only about getting enough calories, but also about getting the right macronutrients. Protein is one of the most important macronutrients, but producing that much protein is a big problem. Animal proteins are considered to be of high quality, but the resources necessary to maintain a constant need are insufficient (Alcorta *et al.*, 2021) To solve this problem, an alternative source of protein must be found as needed. Plant proteins are a promising solution because they can be easily grown with lower productivity costs and are also environmentally friendly.

The quality of protein depends on the amino acids it contains, and the human body contains 20 amino acids, which are further classified into essential and non-essential amino acids. Essential amino acids are synthesized in our body and are not needed mainly through external food; which contains alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, proline, serine and tyrosine. On the other hand, essential amino acids are not produced by our body and should be obtained through external food. This group includes histidine, leucine, isoleucine, valine, lysine, phenylalanine, methionine, threonine and tryptophan (Hoffman *et al.*, 2004). The nutritional value of proteins depends on their amino acid content, bioavailability, purity, digestibility, nutritional factor

(substances that, if present, affect the availability of proteins by themselves or through some metabolic reaction), etc. Animal proteins such as eggs, meat, poultry, milk and fish contain complete and high-quality proteins because they provide all the essential amino acids. But they also contain fats and cholesterol, which threaten human health and can cause heart disease, high blood pressure, stroke, etc. The increase in animal proteins is also related to depletion of natural resources, damage to biological diversity, climate crisis, depletion from fresh water etc. (Sá *et al.*, 2020). Therefore, there has been a recent shift to plant proteins. However, these proteins lack one or more essential amino acids. Replacing plant proteins with animal proteins presents different challenges. It is very important in terms of protein content, and the quality must be intact during handling during various treatments. Processing and raw costs must be affordable. Plant-based protein food should be tasty, spices can be added for taste. It should be easy to digest and accessible. The effects of anti-nutrients and allergens should be minimized (Hertzler *et al.*, 2020). People who depend entirely on plant proteins should have a varied plant-based diet, meaning they should have all types of plant-based foods, including legumes, grains, seeds, nuts, various fruits and vegetables, etc., to meet their protein needs.

Plant proteins are an excellent source of protein that is lower in fat and cholesterol. As the world population increases every day and to ensure safe and nutritious food for the current population without negative environmental impact and to maintain a healthy ecosystem, it is important to replace traditional animal proteins and develop proteins with better digestibility and bioavailability. Plant proteins are lower than animal proteins and are often considered incomplete. Therefore, protein products are developed using advanced techniques by mixing different plant proteins (Langyan *et al.*, 2022). When developing new protein preparations, it is important to note that the protein must remain stable and active during transport, storage and administration in the human body, as these proteins are prone to degradation.

Major plant protein sources

Legumes: Legumes belong to the Leguminosae family. They play an important role in the human diet due to their high protein content as well as certain minerals, vitamins and calories. Legumes are considered the poor man's meat because they are a rich source of protein at an affordable price (Jaborova *et al.*, 2020). Some common legumes are beans, peas, pigeon peas, chickpeas, peas, beans, soybeans, lentils, mung beans, Kidney, cowpeas and black gram (Singh *et al.*, 1992).

Lentils : Lentils are legumes that belong to the family Leguminosae. Their structure resembles a lens, thus the name "lentil". There are several varieties of lentils on the market that may be eaten. Among the most often utilized are red lentils, yellow pigeon peas, black and green gram, bengal gram and green gram beans. While lentils are low in sulfur-containing amino acids like cysteine and methionine, they are high in important amino acids like phenylalanine, leucine, threonine and lysine. Minerals including iron, potassium, phosphorus, zinc and others are also present in lentils. They are also excellent providers of vitamin B. Lentils are commonly consumed with cereals because they provide a complete protein supply (Samaranayaka *et al.*, 2016).

Soy proteins : Legumes produced for oil extraction and as pulses are called soy beans. Soy beans have the greatest protein content of any grain or legume, ranging from 34 to 37%. They also include dietary fibre and carbs. A little additional processing is required for human consumption before other soy products, such as soy milk for kids, soy flour, soy concentrates, tofu and soy isolates, are produced. Methionine and cysteine are two examples of amino acids low in sulphur that are found in soy proteins, such as storage proteins like β -conglycinin and glycinin, which possess the majority of necessary amino acids. Other trace amounts of protein include lectins and lipoxigenase; however, these are eliminated since they might alter the nutritional value and flavour of proteins (Thrane *et al.*, 2017).

Cereals : Cereals are edible seeds that are members of the Gramineae grass family. They are also sometimes referred to as grains. A basic food that offers nutrients including carbohydrates, proteins, vitamins, and minerals. Some of the major grains are wheat, barley, maize, rice, oats, etc.

Wheat is another significant cereal that is eaten as chapati, bread, noodles, pasta and other foods (Jaborova *et al.*, 2020). The primary storage protein found in wheat is gluten; additional proteins include albumin, gliadins, and globulin. Leucine, valine and isoleucine are the other amino acids that include sulphur, where as lysine is found in less amounts. The easily obtainable necessary amino acid L-glutamine is thought to be crucial for athletes and aids in boosting immunity (Nadathur *et al.*, 2016). Pseudo cereals are safe for celiac disease sufferers and may be fed to babies because they are gluten-free. Quinoa, buckwheat and amaranth are examples of pseudo cereals.

Oil seeds : Oil seeds are rich in sulfur-containing amino acids and are a good source of protein. They possess neuroprotective, antihypertensive, and antioxidant

qualities. Among the oil plants utilised as a source of protein include sunflower, rapeseed, sesame, safflower, glandless cottonseed, soybean, chia seeds, evening primrose, brown flaxseed, hemp seeds, milk thistle, nigella seeds and pumpkin seeds (Kotecka-Majchrzak *et al.*, 2020).

Why is the importance of plant-based protein?

Environmental benefits : Exploration of plant-based protein sources and the creation of derived protein products would assist to minimise greenhouse gas (GHG) emissions while also conserving the earth's fresh water and land resources. In comparison, animal husbandry emits more greenhouse gases than the whole transportation industry.

Individual health benefits : Plant-based proteins are typically nutritious. A shift towards a more plant-based diet has been linked to improved human health. For instance, a well-planned plant-based diet may aid in the management, prevention, and in certain situations, the reversal or treatment of medical problems including cancer, diabetes, obesity and heart disease. It also reduces/eliminates the intake of possibly dangerous antibiotics from meat eating.

Animal welfare and religious consideration : Reducing animal/livestock killing leads to a more ethically conscious lifestyle (animal welfare). Additionally, for religious reasons, it would give some specific religious groups with dietary restrictions (such as Hindu, Sikh and other customers) more items and buy alternatives.

Plant protein alternatives as supplements

Animal-based dietary items are regarded as the traditional source of proteins. Around the world, a sizable number of diets consist of meat. However, a number of health issues have forced the substitution of plant-based proteins for these animal-based proteins (Table 1). The

list of alternatives based on plant proteins is provided below, along with a discussion of each one's benefits and drawbacks.

Shifting towards novel protein sources

Protein is one of the most important ingredients in meat substitutes. The processes of hydration, solubility, emulsification, foaming, taste binding, viscosity, gelation, texturization and dough formation are all significantly influenced by proteins (Meade *et al.*, 2005).

Soy protein : Proteins that are both soluble and insoluble in water make up soybeans. Proteins in soybeans are separated into storage globulin and whey fractions during acidification at pH 4.5–4.8. Sedimentation coefficient is used to categorise globular proteins into four groups: 2S, 7S, 11S and 15S. 7S (β -conglycinin) and 11S (glycinin) make up 80% of protein (Nishinari *et al.*, 2014). Burgers, sausages and meat substitutes like sausages are made from soy protein isolates and concentrates. Products made from soy, such as soy milk and flour, are used to make components that are high in protein. Soymilk is coagulated to create tofu, which is high in protein, calcium and iron. When cooked, it forms a gel-like structure that absorbs all flavour. Another product made from soy is tempeh, which is made by fermenting cooked soybeans and grains like millet and rice with the help of *Rhizopus oligosporus* as a culture organism. Since, soy beans are used to make both tempeh and tofu, they have a meatier flavour (Purwadaria *et al.*, 2016). The thin skin that develops on top of heated soy milk is layered to make yuba, a soy-based alternative meat substitute (Hoek *et al.*, 2011).

Wheat protein : As a meat substitute, wheat gluten, a byproduct of wheat starch, is crucial. It provides viscosity, forms dough and acts as a binding agent. Protein that is insoluble is left behind when soluble components are washed with water to remove gluten (Barak *et al.*,

Table 1 : List of plant-based protein alternatives (Mistry *et al.*, 2022).

Product	Plant based alternative	Advantages	Disadvantages
Cheese	Protein from peanut, soy and vegetable fat	Good potential for lowering the lipid profile Minimal production costs	The amount of nutritious content may be low.
Egg	Proteins from flax seeds, peas and sunflower seeds	Egg-like functional qualities (emulsification, foaming) Low fat level	Contains an anti-nutritional substance
Milk	Soy, almonds, coconut	Suitable for digestive disorders (lactose intolerance), Ideal for vegan milk sources.	Less palatable if unflavoured
Microalgae	<i>Chlorella</i> sp. <i>Spirulina</i> sp.	Need less land High protein content.	Genetically modified microalgae may provide regulatory challenges.

2014). The gluten in dough transforms into fibrous structure during the extrusion or shear cell process, giving it a feel close to meat, and is utilised to make alternatives to whole-cut and minced types (Klose and Arendt, 2012). Disulphide protein forms a 3D cross link as a result of fibrous structure creation during the high-extrusion process (Wang *et al.*, 2017).

Legume protein : Legume protein may be found in legumes such as chickpeas, faba beans, lentils, and lupins. Because pea protein can bind fat and water to obtain a solid texture that can tolerate heat processing, it might be thought of as a versatile legume protein (Nadathu *et al.*, 2016). The cultivation, extraction method, and composition (ratio of legumin to vitellin) of peas determine their functionality and utility (Cui *et al.*, 2018). The desired functionality of legume protein can be obtained by the use of less refined protein-rich substances (Makri *et al.*, 2005), a combination of ingredients (Li and Wang, 2019), or post-processing heat treatment (Bühler *et al.*, 2020).

Algae protein : Microalgae can create up to 70% of the proteins in cells, compared to 30-40% for soybeans, depending on the strain and culture circumstances. *Spirulina (Arthrospira)* and *Chlorella* are the most popular microalgae species with 102.6 and 107.5 essential amino acid index, which is higher than average index 100 (Kent *et al.*, 2015).

Techniques

Spinning process : Wet spinning and electrical spinning are the two categories of spinning processes that are based on the alignment of the biopolymer solution. Boyer was granted a patent in 1954 for the wet spinning of proteins for use as a meat substitute. A protein-containing solution is extruded using a spinneret, and it is then immersed in a non-protein-solvent bath. Stretched filaments with a thickness of around 20 μ m are produced when the extruded protein phase precipitates and solidifies due to exchange between solvent and non-solvent (Rampon *et al.*, 1999). Biopolymer solution is pushed through an electro spun needle, also known as a spinneret, that is hollow and has an electric potential in connection to a ground electrode. Surface instabilities cause the formation of very thin fibres (less than 100 nm), which are attracted to the ground electrode (Schiffman and Schauer, 2008). These fibres serve as a meat substitute. Whey, collagen, eggs, and gelatin are proteins that are electro spun; plant proteins are not frequently utilised in this process (Ghorani and Tucker, 2015). Proteins are difficult to electro spin; hence they are combined with spinnable polymers such as cellulose and malt dextrin to improve the technique's efficiency (Kutzli *et al.*, 2020).

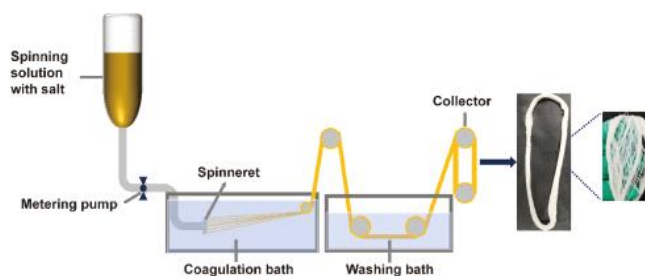


Fig. 1 : Spinning process of making texturized plant-based meat fibrous (Cui *et al.*, 2023).

Extrusion : Extrusion is the most common technique for producing TVPs. It is a high-output, reasonably priced, and energy-efficient approach. Water, salts, binders, lipids, flavours and stabilisers are added to create TVPs. The extruder screw, which produces the goods with the appropriate structure and form under the influence of high temperature and pressure, is where the raw components are permitted to pass. There are two forms of extrusion structuring: high-moisture extrusion and low-moisture extrusion. Furthermore, extrusion denatures heat-labile antinutritional factors as hem agglutinins and trypsin inhibitors, enhances protein digestibility, and inactivates hydrolytic enzymes such as lipoxygenases, peroxidases and lip oxidases (Mazaheri *et al.*, 2019). By using low-moisture extrusion, flour or concentrates are turned into TVP, a dry, slightly enlarged product with a spongy feel, which is subsequently moistened. High-moisture extrusion produces products that resemble fibrous meat and weigh at least 50%. The protein inside the barrel is plasticized via a mix of mechanical deformation, hydration, and heating. High temperatures (140–180°C) during extrusion are used to guarantee



Fig. 2 : Extrusion technique of making texturized plant-based meat analogues (Arora *et al.*, 2020).

protein melting and polymerization. But as a drawback of this method, it also results in colour changes because of the Maillard reaction, caramelization, hydrolysis, and pigment degradation (Cheftel *et al.*, 1992).

Shear Cell Technology : The procedure is carried out in a Couette cell, which has a cylindrical shape, or a shear cell, which is a conical device based on a cone plate remoter. Heat and simple shear are used to create fibrous structure (Krintiras *et al.*, 2014). The primary determinant of a solid anisotropic food texture is the heating temperature (140°C), while a low temperature produces a layered structure (Grabowska *et al.*, 2014).

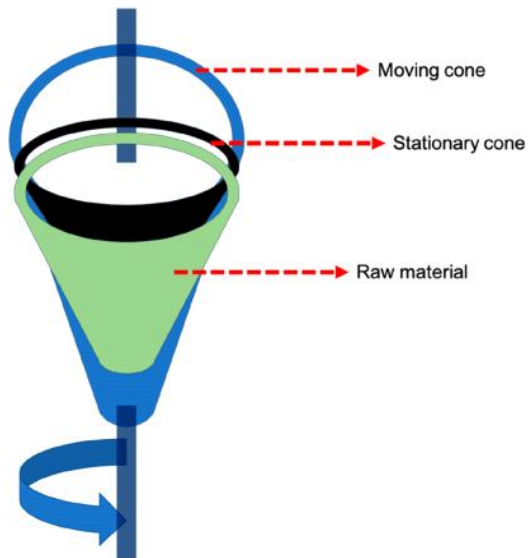


Fig. 3 : Conical shear cell technique and Couette cell technique (Arora *et al.*, 2020).

Freeze structuring : Freeze structuring is the process of freezing a protein slurry. Anisotropic structure forms, when slurry is heated without mixing, whereas isotropic structure is produced when heat is withdrawn from well-mixed slurry. The formation of ice crystal needles is dependent upon freezing temperature and pace (Lugay and Kim, 1978). The fibrous nature of the protein is stabilised by high-temperature drying, which also keeps the ice crystals from melting. By altering the freezing circumstances, such as the freezing rate, pH, solids content of the material, surface and heat exchange effects, degree of condensation and pressure effects, protein textural properties may be changed (Boyer *et al.*, 1975).

Factors to consider

Sensory factors and consumer acceptability :

Plant proteins usually have off-notes; it is critical to understand the components and the procedure employed in order to give exceptional taste and flavour while keeping a decent nutritional profile and regulating salt and fat levels.

Technical obstacles : The key is to create a meat-like structure/texture, as well as a meat-like look and flavour. Nowadays, the food industry uses extruders extensively. Wet spinning, 3D printing, and shear cell technology are among the other cutting-edge innovations now in development.

Food allergies and food safety : 1) Allergen information must be clearly displayed on items. Customers may be allergic to wheat, soy, or other components. 2) As plant-based meat substitutes often offer a high moisture content and neutral pH, there is a greater chance of microbial growth and reproduction. Additional heat treatment is advised following the post-extrusion procedure and before non-sterile substances are added (Bogueva and McClements, 2023).

Anti-nutritional factors (ANF) : Plant protein sources, particularly legumes, include significant levels of ANFs (such as phytic acid, tannins, phenols and trypsin inhibitors). These ANFs have the ability to decrease the digestion and absorption of minerals (such as zinc and iron) and proteins/amino acids. It is possible to eliminate ANFs and/or reduce their effects by employing various processing techniques (Samtiya *et al.*, 2020).

Protein quantity vs Protein quality : Protein quality is sometimes overlooked in favour of daily protein consumption and the amount of protein found in various protein sources. 1) Nutritional profile and balance: Some plant proteins are not complete proteins (they do not include all required amino acids) and since they lack specific micronutrients, they may result in vitamin B12 and iron deficiencies. 2) Digestibility and bioavailability: The effectiveness of protein digestion is a measure of its quality and is linked to sustainable production as well as health (Hertzler *et al.*, 2020).

Conclusion

The global food system will confront enormous challenges in the next decades as it works to feed a swelling population of more than 10 billion people by 2050. More than ever, there is a need for ethical food production that takes environmental issues and climate change into account. The Fourth Industrial Revolution offers a potential way to address these issues and change the food system thanks to its technical breakthroughs. There is growing interest in alternative proteins as ways to reduce the environmental effect of meat production while also promoting healthy diets. While shear cell and extrusion processes are two often researched structuring methods, selecting the appropriate protein sources, controlling chemical and biological safety, and optimising overall flavour and appearance are all critical for the

production of plant-based alternatives. Consumer acceptability of plant-based substitutes is increasing, despite the fact that it is still insufficient. Future research opportunities include improving consumer education, providing scientific evidence for plant-based alternatives' health properties, identifying suitable protein sources to enhance product quality, improving appearance and flavour, ensuring chemical safety, and investigating structure formation during extraction or shearing. However, there are certain challenges to overcome, such as consumer acceptability, regulatory issues, and potential dangers to livelihoods in certain places. It is imperative to address the reduction of meat consumption and the changeover to meat replacements with consideration for the health and welfare of vulnerable people, including those who depend on livestock for a living. Future food systems may be made healthier and more sustainable by implementing a comprehensive plan that integrates socioeconomic factors, customer engagement, and technological innovation.

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