WORLD JOURNAL OF PHARMACEUTICAL RESEARCH
SJIF Impact Factor 8.453
Volume 14, Issue 3, 100-114. Review Article ISSN 2277–7105

A REVIEW ON USING PLANT LEAF PROTEINS FOR HUMAN CONSUMPTION AS A SUSTAINABLE ALTERNATIVE TO ANIMAL PROTEINS

Shaik Muneer*, D. Nagur Vali[1], D. Sankar Naik[1], Soram Ariyal Singh[1] and B. Thangabalan[1]

*Assistant Professor, Department of Pharmaceutical Analysis, SIMS College of Pharmacy, SIMS Group of Institutions, Mangaldas Nagar, Guntur,-522001, Andhra Pradesh, India.

[1]Principal and Professor, Department of Pharmaceutical Analysis, SIMS College of Pharmacy, Mangaladas Nagar, Guntur, Andhra Pradesh, India.

Article Received on
15 Dec. 2024,

Revised on 05 Jan. 2025,
Accepted on 26 Jan. 2025

DOI: 10.20959/wjpr20253-35343

***Corresponding Author**
Shaik Muneer
Assistant Professor, Department of Pharmaceutical Analysis, SIMS College of Pharmacy, SIMS Group of Institutions, Mangaldas Nagar, Guntur,-522001, Andhra Pradesh, India.

ABSTRACT

Most of the agroclimatic conditions without requiring much agricultural inputs. It's functional properties are unique and finds application in novel food product formulations. : Plant proteins can meet consumers' demand for healthy and sustainable alternatives to animal proteins. It has been reported to possess numerous health benefits and is widely used in the food industry. Proteins are essential nutrients in the human diet, on demand for environmentally friendly, nutritious, sustainable, and humane choices, the plant proteins industry has grown rapidly over the past decades. Plant proteins are gradually replacing animal proteins as an emerging option. Common sources of plant proteins mainly include pulses (pea, fava bean, lentil, lupin, and chickpea), cereals (wheat, corn, rice, barley, sorghum, rye, oat, and millets), pseudocereals (quinoa, amaranth, buckwheat, and chia seeds), seeds (chia, linseed, sesame, pumpkin, and sunflower), nuts (almonds, cashew, and peanut) etc…, plant parts such as seeds have commonly been used; however, a novel source of plant protein is related to leaves. These are widely used in animal feed, especially for ruminants, but some studies have demonstrated the use and benefits of plant leaves in human food. Increasing the yield of food crops has its limitations, including low acceptance of genetically modified crops, land availability for cultivation, and the need

for large quantities of agrochemicals. On average, the protein content of plant leaves is similar to that of milk, which can be efficiently tapped for food applications across the globe. There has been limited research on utilizing plant leaf proteins for food product development. The present study thoroughly reviews the opportunities and challenges linked to the production of plant leaf proteins, including its nutritional aspects, extraction and purification strategies, nutritional factors, its applications and disadvantages and finally, its impact on the environment. Practical Application: Plant leaf proteins are one of the sustainable and alternative source of proteins. It can be produced.

KEYWORDS: Plant Leaf Proteins, novel food product formulations, Healthy and sustainable alternatives, Animal proteins.

1. INTRODUCTION

Protein deficiency is one of the major nutritional problems in the developing world. It is estimated that nearly one billion people over worldwide suffering with protein deficiency. In India it was discovered that 54% of Indian children are not growing properly, being either underweight, too short for their age, or overweight. The protein malnutrition manifests itself in forms of two notorious diseases: Marasmus and kwashiorkor. In most under developed countries, the majority of the people are vegetarian and even where it is possible to obtain meat price is too high that most families do not have meat more than once a week. The process of photosynthesis is the only non depletable protein source and can supply some essential amino acids as well as provide adequate nitrogen in the diet for synthesis of non essential amino acids in addition to vitamins and minerals. Proper use of the growing season can achieve high protein yield. Green leaves are an abundant but underexplored source of alternative proteins Therefore, expansion of present agricultural practices into marginal lands is expected to solve this chronic world food shortage. However, only a very small percentage of the world edible plants are being utilized for human food.[1-3]

Leaf Proteins:- Plant leaf proteins can be a valuable source of nutrition for humans, and research into extracting and utilizing these proteins has been growing in recent years. While most plant proteins come from seeds, legumes, and grains, certain plant leaves are particularly rich in proteins and can be used in various ways to supplement human diets. Proteins are essential macromolecules made up of amino acids, which are vital for the structure, function, and regulation of the body's cells, tissues, and organs. They play a key role in building and repairing tissues, supporting immune function, acting as enzymes and

hormones, and providing energy when need Proteins are essential because they supply amino acids that the body cannot synthesize on its own. These include nine essential amino acids that must be obtained from the diet Protein deficiency can lead to a variety of health issues. In children, it can cause stunted growth, weakened immunity, and developmental delays. In adults, it can lead to muscle wasting, fatigue, and impaired healing. Severe protein deficiency can result in conditions like *kwashiorkor* and *marasmus* Protein deficiblood plasma, insulin and hormones are all proteins or composed primarily of protein.

AMINO ACIDS:- There are 20 amino acids useful to humans, some of which are essential. An essential amino acid is one that cannot be synthesized by the organism and must, therefore, be supplied in the diet. Eight amino acids are essentials: Isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine and lucine. Cysteine (sulphur containing amino acid), tyrosine (aromatic amino acid), histidine and arginine are required by infants and growing children. The amino acids arginine, cyteine, glycine, glutamine, histidine, proline, serine and tyrosine are considered (conditionally essential, meaning that they are not normally required in the diet but must be supplied exogenously to specific populations that do not synthesize them.

ESSENTIAL AMINO ACIDS	NON ESSENTIAL AMINO ACDS
Isoleucine	Alanine
arginine	Aspartate
lysine	Cysteine*
methionine	Glutamate
phenylalaine	Glutamine*
threonine	Glycine*
Tyrosine*	Proline*
tryptophan	Serine*
Histidine*	Asparagine*
valine	Selenocysteine*
lucine	

2. **METHODS FOR EXTRACTION OF PLANT LEAF PROTEINS:** The extraction of plant leaf proteins for commercial production involves several methods, with the choice of method depending on factors such as the plant source, desired protein quality, and the scale of production.the most common methods are.[4-6]

SOLVENT EXTRACTION METHOD

This method uses solvents, usually aqueous solutions or organic solvents, to dissolve proteins from plant tissues. The plant material is ground into a powder and treated with a solvent

(water, ethanol, or salt solution). The proteins are solubilized into the liquid phase, while insoluble materials are filtered out.

ALKALINE EXTRACTION

This method uses alkaline solutions (such as NaOH or KOH) to extract proteins from plant tissues by increasing the pH. The plant material is treated with an alkaline solution, causing proteins to solubilize. The pH is then adjusted back to neutral, causing the proteins to precipitate out, which can be collected through centrifugation.

ACID EXTRACTION

An acidic solution (such as citric acid or hydrochloric acid) is used to extract proteins by lowering the pH. The plant material is treated with an acid, which solubilizes proteins. The solution is then neutralized, and proteins can precipitate and be separated.

ENZYMATIC EXTRACTION

Enzymes are used to break down cell walls and release proteins. Plant material is treated with specific enzymes (e.g., cellulase, pectinase) to degrade the plant cell wall, allowing the proteins to be extracted into the solution.

MECHANICAL EXTRACTION (COLD PRESSING OR EXPELLER PRESSING)

Mechanical methods use physical force to separate proteins from plant material, often combined with minimal heat. The plant material is mechanically pressed (e.g., with a screw press or expeller press), which separates the oil and proteins from the rest of the plant tissue.

ISOELECTRIC POINT PRECIPITATION

Proteins are precipitated by adjusting the pH to their isoelectric point (the pH at which the protein has no net charge). After initial extraction, the pH of the solution is adjusted to the isoelectric point of the target proteins. This causes proteins to precipitate, which can then be separated by centrifugation or filtration.

ULTRAFILTRATION AND MEMBRANE FILTRATION

This method uses selective membrane filtration to separate proteins based on size. A membrane is used to filter out proteins from other solutes in an aqueous solution. This method is often used after initial extraction to concentrate proteins.

SPRAY DRYING AND FREEZE DRYING (DRYING TECHNIQUES FOR CONCENTRATES)

After extraction, plant proteins are often concentrated and then dried for commercial production. The protein solution is sprayed through a hot air stream (spray drying) or frozen and sublimed (freeze drying) to remove moisture and produce protein powder.

SUPERCRITICAL FLUID EXTRACTION

Supercritical CO_2 is used to extract proteins by exploiting its solvent properties at high pressure and temperature. Carbon dioxide is used in a supercritical state (between liquid and gas) to extract proteins, usually after a mild extraction process has been carried out.

HYDROTHERMAL TREATMENT

The plant material is treated with heat and pressure in water to break down cell walls and release proteins. The plant material is subjected to high temperature and pressure, which helps to release proteins while potentially modifying their structure for better digestibility.

However, the efficiency and suitability of each method will depend on factors like:

- The leaf type (e.g., soft vs. tough leaves),
- The desired proteins (e.g., structural vs. soluble proteins),
- The industrial scale (e.g., lab-scale vs. commercial production),
- Protein functionality (e.g., retaining bioactivity, flavor, or texture).

For optimal results, often a combination of these methods (e.g., enzymatic extraction followed by ultrafiltration) is used to enhance protein yield, quality, and purity, making it suitable for applications in **food, feed**, or **biotechnology** industries.

3. PROTEIN CONTENT IN DIFFERENT PLANTS[7-10]

1. **Moringa Leaf Protein**:

- **Moringa oleifera**, often called the "drumstick tree" or "miracle tree," is a nutrient-dense plant. The leaves are particularly rich in proteins, containing all the essential amino acids, making it a complete plant-based protein source. Moringa leaves also provide vitamins (like vitamin C and A), minerals (such as calcium, potassium, and iron), and antioxidants.
- **Moringa protein** is increasingly being explored for use in dietary supplements, protein powders, and functional foods due to its high nutritional value. Moringa protein is also digestible and relatively easy to extract from the leaves.

2. **Spinach Leaf Protein**
   - **Spinach** (**Spinacia oleracea**) is another leafy green that contains a variety of proteins, including enzymes involved in photosynthesis (like rubisco) and structural proteins. While spinach doesn't contain as much protein per serving as legumes or grains, it still contributes beneficial protein to the diet, especially when consumed in larger quantities.
   - **Spinach protein** is also a good source of various vitamins, iron, and antioxidants. Research is looking into extracting spinach protein for use in protein-rich food products like smoothies and snack bars.

3. **Lettuce and Kale Leaf Proteins**
   - **Kale** and other leafy greens like **lettuce** also contain moderate amounts of proteins. Kale, in particular, has a higher protein content than other greens and is increasingly being used in the plant-based food industry. It is also a good source of vitamins (especially K and C), minerals, and fiber.
   - **Kale protein** While the protein content is lower compared to seeds and legumes, kale and lettuce proteins are still significant when consumed as part of a varied diet.

4. **Alfalfa Leaf Protein**
   - **Alfalfa** (**Medicago sativa**) is widely used for its high protein content, especially in animal feed, but its leaves are also consumable by humans. Alfalfa leaf protein contains important amino acids and can be extracted for use in plant-based protein powders or food supplements.
   - **Alfalfa protein** is rich in vitamins, including B vitamins and vitamin K, and offers benefits for digestive health due to its fiber content.

5. **Pea Leaf Protein**
   - **Pea** (Pisum sativum) plants are primarily known for their seeds, but pea leaves also contain a significant amount of protein. Pea leaf protein is a subject of ongoing research, particularly as part of efforts to explore alternative plant-based protein sources that are sustainable and efficient to produce.
   - **Pea protein** (often extracted from the seeds) is already popular in plant-based protein powders, and pea leaf protein may find similar uses in the future as it can be a complementary source.

PLANT LEAFS	PROTEIN CONTENT
Moringa leaves	16-40%
Lentils	25-30%
Spinach	50%
Lettuce	24%
Pea leaf	50-70%
Alfalfa leaf	19.2-21.8%
Jack fruit leaf	13-28%
Raddish leaf	48.3%
Duck weed	20-35%
Sugar beet	20%
Amaranth	10.7%
Tea	17.5-25.4%
Cabbage	5.60%
Cassava	16.7-39.9%
Pumpkin leaf	21.3%
Soybeen leaves	48.4%
Cowpea leaves	29-43%
Mustard greens	20.6-33.3%
Basil leaves	44%
Okra leaves	13.56%
Bamboo leaves	8.12-16.33%
Chaya leaves	27-34%
Sweet potato leaves	24.8%
Grape leaves	20%
Mulberry leaves	15-35%
Sage leaves	22%
Curry leaves	10-18%
Taro leaves	16-27%
Purslane leave	18%
Bitter melon leaves	27%
Sacha inchi leaves	22-30%
Wheat grass	8%
Fennel leaves	5.94-7.82%
Kang kong	6.3%
Lamb's quarters	4-5%
Thyme leaves	5-10%
Chili pepper leaves	4%
Cucumber leaves	3.33%
Cress leaves	3%

4. APPLICATIONS OF PLANT LEAF PROTEIN AT INDUSTRIAL SCALE[10-14]

The **best application** of using plant leaves as a protein source for human consumption on an industrial scale is likely the **production of plant-based protein powders and supplements**. Here's why:

1. High Demand for Plant-Based Proteins

There is an increasing global demand for plant-based protein products due to the rise in veganism, vegetarianism, and flexitarian diets. Consumers are more conscious of their environmental impact and health, and plant-based proteins provide a sustainable, cholesterol-free alternative to animal proteins.

2. Versatility in Formulation

Plant leaf proteins, like those from **moringa**, **spinach**, and **amaranth**, can be easily processed into protein powders. These powders can then be incorporated into a wide range of products, such as smoothies, shakes, and energy bars. This versatility allows for customization according to consumer needs (e.g., protein for muscle recovery, weight management, or general health).

3. Sustainability

Using plant leaves, especially from fast-growing plants like **moringa**, as protein sources is environmentally sustainable. These plants typically require fewer resources (water, land, and energy) compared to traditional animal protein sources. This aligns with the growing demand for sustainable food production to address global food security and environmental challenges.

4. Health Benefits

Many plant leaves are not only rich in protein but also contain other essential nutrients such as vitamins, minerals, and antioxidants. For example, moringa leaf powder is known for its high levels of vitamins A, C, and E, and its anti-inflammatory and antioxidant properties, making it a highly nutritious protein source.

5. Ease of Scale-Up

Plant leaf-based protein powder production can be scaled up relatively easily. The plants are often fast-growing, requiring minimal processing, and they are available in many parts of the world, making it feasible for large-scale, cost-effective production.

6. Global Market Appeal

With the growing popularity of plant-based diets and supplements, products like plant-based protein powders have a large and expanding market worldwide. From athletes and fitness enthusiasts to individuals seeking healthier lifestyle choices, plant leaf protein powders can serve a broad audience.

7. Nutritional Fortification

These protein powders can also be used to fortify a wide range of everyday foods such as cereals, baked goods, and dairy substitutes, increasing their protein content and providing a natural, sustainable source of protein.

MOSTLY USED IN THE FORM OF

1. **Plant-Based Protein Powders**: Plant leaves, especially from moringa, spinach, and amaranth, can be processed into protein powders. These powders can be used in the formulation of protein shakes, supplements, and sports nutrition products, offering a vegan-friendly, environmentally sustainable alternative to whey and other animal-based proteins.
2. **Functional Foods and Beverages**: Leaf-based protein can be incorporated into functional foods and beverages, such as protein-enriched juices, smoothies, and energy drinks. This allows consumers to easily add more plant-based protein to their diet in convenient, ready-to-consume formats.
3. **Protein-Enriched Bakery Products**: Plant leaf proteins can be incorporated into flour to create high-protein bakery products like bread, muffins, pancakes, and cookies. This fortification enhances the nutritional content of everyday items, offering an affordable way to improve protein intake.
4. **Protein-Rich Plant-Based Meat Alternatives**: Using leaf protein in the formulation of plant-based meat substitutes, such as burgers, sausages, and nuggets, helps improve the texture, flavor, and nutritional profile of these products. Leaf protein contributes to the overall protein content and can mimic the texture of animal proteins.
5. **Nutraceuticals and Dietary Supplements**: Plant leaf proteins, such as those from moringa and spirulina, are increasingly used in the production of nutraceuticals—products that combine nutrition and medicine. These can be marketed as dietary supplements for boosting protein intake, enhancing immune function, and improving overall health.
6. **Ready-to-Eat (RTE) Meals**: Pre-packaged RTE meals that are rich in plant-based proteins from leaves can cater to the growing demand for convenient, nutritious, and sustainable food options. These meals may include leaf proteins in soups, stews, or casseroles.
7. **Texturized Protein Products**: Leaf proteins can be processed into texturized protein (similar to texturized vegetable protein or TVP) to create meat-like products. This texture

is ideal for applications in ready meals or meat analogs, offering a low-cost and sustainable option for plant-based protein in the food industry.

8. **Protein-Enriched Snacks**: Plant leaf protein can be incorporated into snack foods like chips, crackers, and protein bars. This helps create protein-rich snack options for health-conscious consumers, athletes, and those seeking alternative protein sources.
9. **Fortification of Baby and Toddler Food**: Leaf-based protein powders can be used to fortify baby foods, including purees and cereals. This can help address protein deficiencies in vulnerable populations, especially in areas with limited access to animal-based protein.
10. **Protein-Rich Pasta and Noodles**: Plant leaf protein can be incorporated into the production of pasta, noodles, and other staple carbohydrate-rich foods. This enhances the nutritional value of these commonly consumed products by adding a plant-based protein component.

Example in Practice

Moringa Protein Powder: Moringa leaf protein powder is already gaining traction as a superfood ingredient due to its high protein content and rich nutrient profile. It is used in protein shakes, smoothies, snack bars, and health supplements, making it one of the most successful and effective applications of using plant leaves for human consumption on an industrial scale.

Additional Benefits of Industrial Applications

1. Improved Food Security

- **Diversified Protein Sources**: Plant leaf proteins can help reduce reliance on traditional animal proteins, which are often expensive and resource-intensive. They offer a more accessible and sustainable option, particularly in regions facing food insecurity or where animal farming is not feasible.
- **Addressing Malnutrition**: Leaf proteins are nutrient-dense and can be used to address protein malnutrition, especially in developing countries where animal-based proteins might be scarce. By adding plant leaf proteins to everyday foods, the risk of protein-energy malnutrition can be reduced.

2. Lower Environmental Impact

- **Reduced Greenhouse Gas Emissions**: Plant-based protein production generates fewer greenhouse gases compared to animal agriculture. By switching to plant leaf proteins, the overall carbon footprint of food production is significantly lowered.
- **Efficient Land Use**: Growing plants for leaf protein requires less land compared to raising animals for meat or dairy. This reduces deforestation and land degradation, both of which are major environmental issues tied to conventional animal agriculture.

3. Cultural Acceptance and Accessibility

- **Culturally Adaptable**: Plant-based proteins from leaves can be easily incorporated into traditional dishes across different cultures. This makes them more accessible to diverse populations and allows for easy integration into local diets without major changes to food habits.
- **Affordable Option**: Leaf proteins are often more cost-effective to produce than animal proteins, making them a viable solution for feeding low-income populations, especially in resource-constrained regions.

4. Healthier Alternative to Animal Proteins

- **Lower in Fat and Cholesterol**: Plant leaf proteins are naturally lower in saturated fats and cholesterol compared to animal-based proteins. This makes them heart-healthier and suitable for people looking to reduce their intake of animal fats.
- **Rich in Fiber**: Many plant leaf proteins come with the added benefit of dietary fiber, which helps with digestion, blood sugar regulation, and overall gut health.
- **Antioxidants and Phytonutrients**: In addition to being rich in protein, many plant leaves (e.g., moringa, spinach, and kale) contain powerful antioxidants and phytonutrients that help protect against oxidative stress and reduce the risk of chronic diseases such as cancer and heart disease.

5. No Risk of Antibiotics or Hormones

- **Hormone-Free**: Unlike animal-based proteins, plant leaf proteins are free from the hormones and antibiotics often used in livestock farming. This makes plant leaf proteins a cleaner, safer option, particularly for those concerned about the potential impact of these substances on human health.

6. Support for Biodiversity

- **Increased Crop Diversity**: By promoting the cultivation of a variety of protein-rich plants, such as moringa, amaranth, and quinoa, the demand for leaf protein can help support agricultural biodiversity, reducing the over-reliance on monoculture crops like wheat, corn, or soy.
- **Soil Health**: Many plants used for leaf protein production are known for being hardy and able to thrive in diverse soil conditions, and their cultivation can improve soil health through crop rotation and reducing soil depletion commonly associated with monoculture farming.

7. Innovative Food Products

- **Novel Protein Sources**: The use of plant leaves as protein sources opens up opportunities for new and innovative food products, such as protein-enriched snacks, beverages, and meat analogs. This diversification leads to a broader range of options for consumers with specific dietary preferences or needs.
- **Allergen-Free**: Unlike soy or gluten-based products, plant leaf proteins can serve as allergen-free alternatives for people with sensitivities to soy or gluten, widening the market for plant-based foods.

8. Climate Resilience

- **Drought-Tolerant Plants**: Some plants, like moringa and certain varieties of amaranth, are drought-resistant and thrive in arid conditions. This makes them highly suitable for regions affected by climate change, ensuring a more reliable and resilient protein source in the face of increasingly unpredictable weather patterns.

9. Improved Digestibility

- **Easier to Digest**: Plant proteins, particularly those derived from leaves, are often easier to digest than some animal-based proteins. They tend to have a lower level of complex fats, which makes the digestion process more efficient, especially for individuals with sensitive stomachs or digestive issues.

10. Conservation of Water Resources

- **Water-Efficient**: Growing protein-rich plants such as moringa uses less water compared to raising livestock, which requires vast amounts of water for drinking, feed crops, and overall management. As water scarcity becomes a growing concern, the adoption of

plant-based protein sources can contribute to the conservation of precious water resources.

11. Sustainability

- Plant leaves, especially from crops like moringa, provide a sustainable, eco-friendly protein source compared to animal-based proteins, requiring less land, water, and energy to produce.

12. Cost-Effectiveness

- Many of the leaves used for protein extraction (e.g., moringa, amaranth) are relatively easy to grow and harvest, making them an affordable protein option for large-scale production in comparison to animal proteins.

13. Diverse Consumer Base

- Using plant leaves as protein appeals to vegans, vegetarians, and people with dietary restrictions like lactose intolerance or gluten allergies, expanding the market for plant-based food products

5. CONCLUSION

In conclusion, plant leaf proteins present a promising and sustainable alternative to animal proteins for human consumption. As the global demand for protein continues to rise, driven by population growth and dietary changes, the environmental impact of animal-based protein production, including land use, water consumption, and greenhouse gas emissions, has prompted the exploration of plant-based alternatives. Leaf proteins, derived from various plant species like *Moringa*, *Spinach*, and *Amaranth*, offer high nutritional value with essential amino acids, vitamins, and minerals, making them comparable or even superior to animal proteins in some cases. The advantages of plant leaf proteins include their lower ecological footprint, renewable nature, and potential to diversify the protein sources in our diets. These proteins can be cultivated with fewer environmental resources and could contribute to reducing food insecurity, especially in regions with limited access to animal-based protein. Furthermore, the use of plant leaf proteins could promote sustainable agricultural practices by encouraging the cultivation of diverse crops that enrich soil health and reduce monocropping. However, there are challenges in the widespread adoption of plant leaf proteins, including issues related to taste, texture, and the need for further research on their bioavailability and digestibility. Additionally, scaling up the production and processing of plant leaf proteins for

commercial use requires investment in infrastructure and technology. Despite these challenges, the future of plant leaf proteins as a key component of humannutrition looks promising. As research and development continue, and consumer awareness about the environmental and health benefits of plant-based diets grows, plant leaf proteins may play a pivotal role in the transition toward a more sustainable and resilient global food system.

6. REFERENCES

1. Fukase E., Martin W. Economic Growth, Convergence, and World Food Demand and Supply. World Dev., 2020; 132: 104954. doi: 10.1016/j.worlddev.2020.104954. [DOI] [Google Scholar]
2. Lonnie M., Laurie I., Myers M., Horgan G., Russell W.R., Johnstone A.M. Exploring Health-Promoting Attributes of Plant Proteins as a Functional Ingredient for the Food Sector: A Systematic Review of Human Interventional Studies. Nutrients, 2020; 12: 2291. doi: 10.3390/nu12082291. [DOI] [PMC free article] [PubMed] [Google Scholar]
3. Komarnytsky S., Retchin S., Vong C.I., Lila M.A. Gains and Losses of Agricultural Food Production: Implications for the Twenty-First Century. Annu. Rev. Food Sci. Technol, 2022; 13: 239–261. doi: 10.1146/annurev-food-082421-114831. [DOI] [PubMed] [Google Scholar]
4. Ismail B.P., Senaratne-Lenagala L., Stube A., Brackenridge A. Protein Demand: Review of Plant and Animal Proteins Used in Alternative Protein Product Development and Production. Anim. Front, 2020; 10: 53–63. doi: 10.1093/af/vfaa040. [DOI] [PMC free article] [PubMed] [Google Scholar]
5. Wu G. Dietary Protein Intake and Human Health. Food Funct, 2016; 7: 1251–1265. doi: 10.1039/C5FO01530H. [DOI] [PubMed] [Google Scholar]
6. Food and Agriculture Organization. The State of Food Insecurity in the World: Addressing Food Insecurity in Protracted Crises 2010. Food and Agriculture Organization; Rome, Italy: 2010. [Google Scholar]
7. Berrazaga I., Micard V., Gueugneau M., Walrand S. The Role of the Anabolic Properties of Plant- versus Animal-Based Protein Sources in Supporting Muscle Mass Maintenance: A Critical Review. Nutrients, 2019; 11: 1825. doi: 10.3390/nu11081825. [DOI] [PMC free article] [PubMed] [Google Scholar]
8. Gilani G.S., Cockell K.A., Sepehr E. Effects of Antinutritional Factors on Protein Digestibility and Amino Acid Availability in Foods. J. AOAC Int., 2005; 88: 967–987. doi: 10.1093/jaoac/88.3.967. [DOI] [PubMed] [Google Scholar]

9. Hertzler S.R., Lieblein-Boff J.C., Weiler M., Allgeier C. Plant Proteins: Assessing Their Nutritional Quality and Effects on Health and Physical Function. Nutrients, 2020; 12: 3704. doi: 10.3390/nu12123704. [DOI] [PMC free article] [PubMed] [Google Scholar]
10. Wang Y., Tuccillo F., Lampi A.-M., Knaapila A., Pulkkinen M., Kariluoto S., Coda R., Edelmann M., Jouppila K., Sandell M., et al. Flavor Challenges in Extruded Plant-Based Meat Alternatives: A Review. Compr. Rev. Food Sci. Food Saf., 2022; 21: 2898–2929. doi: 10.1111/1541-4337.12964. [DOI] [PubMed] [Google Scholar]
11. Karthikeyan R, K.O., Babu PS, Chunduru Jayendra. Anti-Inflammatory Activity of Ethanolic Extract of Flowers Hymenocallis Littoralis (Jacq.) Salisb. By Hrbc Membrane Stabilization Method. *Translational Biomedicine*, 2016; *7:* 6.
12. Reiss J., Robertson S., Suzuki M. Cell Sources for Cultivated Meat: Applications and Considerations throughout the Production Workflow. Int. J. Mol. Sci., 2021; 22: 7513. doi: 10.3390/ijms22147513. [DOI] [PMC free article] [PubMed] [Google Scholar]
13. Brahmaiah Bonthagarala, Seetha Devi Alla, Sudarshan Rao Nagineni, Rama Rao Vadapalli, Sri Rekha Malakapurapu, Formulation Optimization and Evaluation of Herbal Films Containing Ethanol Leaves Extract of Cassia auriculata to treat Chronic Constipation Disorder, International Journal of Drug Delivery and Technology, IJDDT, April–June 2024; 14(2): 717-723.
14. Wang Y., Tuccillo F., Lampi A.-M., Knaapila A., Pulkkinen M., Kariluoto S., Coda R., Edelmann M., Jouppila K., Sandell M., et al. Flavor Challenges in Extruded Plant-Based Meat Alternatives: A Review. Compr. Rev. Food Sci. Food Saf., 2022; 21: 2898–2929. doi: 10.1111/1541-4337.12964. [DOI] [PubMed] [Google Scholar]