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Bioactive Peptides from Food Proteins: Extraction, Health Benefits, and Industrial Applications

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Abstract

Bioactive peptides, short chains of amino acids encrypted within food proteins, have emerged as significant biofunctional components with a wide range of physiological benefits. Released during enzymatic hydrolysis, microbial fermentation, or gastrointestinal digestion, these peptides exhibit diverse biological activities, including antihypertensive, antioxidant, antimicrobial, antidiabetic, and immunomodulatory effects. With growing interest in functional foods and natural health-promoting agents, bioactive peptides are increasingly utilized in the food, nutraceutical, and pharmaceutical industries. This review explores the primary sources and advanced extraction techniques of bioactive peptides, elaborates on their mechanisms of action and associated health benefits, and evaluates their industrial applications. Furthermore, the article discusses the current challenges in standardization, bioavailability, and regulatory validation, while highlighting future directions in peptide-based functional product development. As scientific interest and technological capabilities advance, bioactive peptides hold promise for personalized nutrition, preventive healthcare, and sustainable food innovation.

Keywords: *furthermore, standardization, bioavailability, food, nutraceutical, pharmaceutical.*

1. Introduction

Bioactive peptides are emerging as pivotal bio functional compounds with considerable potential in health promotion and disease prevention [1]. These peptides, generally composed of between 2 and 20 amino acid residues, are not biologically active in their native protein configuration. Instead, they are released and activated through specific processes such as enzymatic hydrolysis, gastrointestinal digestion, microbial fermentation, or during food processing operations like fermentation and aging [2]. Once liberated, bioactive peptides can exert various physiological effects, influencing key biological systems and processes in the human body. In recent years, there has been a growing interest in identifying and characterizing bioactive peptides due to their broad spectrum of health-promoting properties. These include antihypertensive (through angiotensin-converting enzyme inhibition), antioxidant (by neutralizing free radicals), antimicrobial (targeting foodborne and pathogenic microorganisms), antidiabetic (modulating insulin activity or glucose metabolism), anticancer, immunomodulatory, and cholesterol-lowering activities [3]. Such multifaceted functionalities make bioactive peptides valuable components in the development of next-generation functional foods, nutraceuticals, and therapeutic agents.

The sources of bioactive peptides are diverse and span both plant and animal-based proteins. Dairy proteins (casein, whey), meat proteins, fish and marine resources, egg proteins, and plant proteins (such as soy, wheat, rice, and legumes) are all recognized reservoirs of bioactive sequences [4]. With the increasing shift toward sustainable food systems and the valorization of by-products from the food industry, the extraction of peptides from underutilized or waste protein sources is also gaining traction. In the context of modern food science and nutrition, bioactive peptides offer a natural, safe, and cost-effective alternative to synthetic additives and drugs [5]. They align well with consumer demand for clean-label, health-enhancing, and minimally processed food products. Moreover, the development of bioactive peptide-enriched products is being accelerated by advances in proteomics, peptidomics, and bioinformatics, which facilitate high-throughput screening, identification, and functional characterization of peptide sequences, the successful integration of bioactive peptides into commercial applications presents several challenges [6]. These include the stability of peptides during processing and digestion, scalability of extraction and purification processes, regulatory approval, and ensuring bioavailability and efficacy in vivo. Addressing these challenges requires multidisciplinary collaboration involving food technologists, biochemists, nutritionists, and industrial stakeholders.

This review article aims to provide a comprehensive synthesis of the current state of knowledge regarding bioactive peptides derived from food proteins. It explores their methods of extraction and production, highlights their health-related functionalities, examines their role in industrial and therapeutic applications, and discusses ongoing challenges and future perspectives in the field [7]. By elucidating these aspects, the review underscores the promise of bioactive peptides in promoting human health and shaping the future of functional food development and biopharmaceutical innovation.

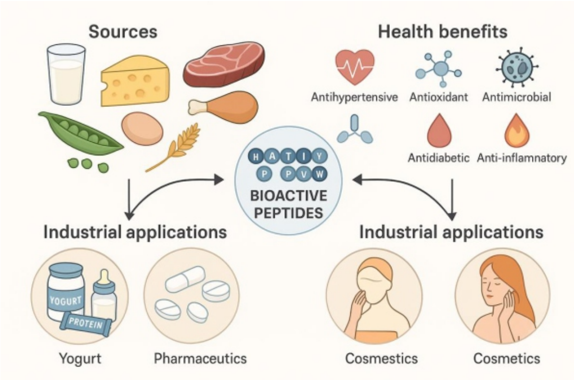

Figure 1: Overview of Bioactive Peptides from Food Proteins – Sources, Benefits, and Applications

2. Sources and Extraction of Bioactive Peptides

Bioactive peptides can be generated from a wide range of protein-rich sources, including both animal- and plant-based materials. Their origin significantly influences their structure, functionality, and potential applications [8]. As these peptides are encrypted within the parent proteins, they require specific processing techniques for release and activation. The identification and extraction of bioactive peptides from food proteins is a growing area of interest, driven by advancements in proteomic tools and sustainable processing technologies.

2.1 Major Sources of Bioactive Peptides

- **Dairy Proteins**: Milk-derived proteins, especially casein and whey, are among the most studied sources of bioactive peptides. These peptides exhibit various health-promoting properties, including antihypertensive, antimicrobial, and immunomodulatory effects. Notable examples include casokinins and lactokinins, which act as angiotensin-converting enzyme (ACE) inhibitors.

- **Egg Proteins**: Egg white proteins, such as ovalbumin, ovotransferrin, and lysozyme, have demonstrated potential for generating peptides with antioxidant, antimicrobial, and antihypertensive properties. Their relative purity and high digestibility make them attractive substrates for enzymatic hydrolysis.

- **Meat and Fish Proteins**: Muscle proteins from beef, pork, poultry, and seafood, as well as collagen-rich tissues, have been successfully used to generate bioactive peptides with antioxidant, anti-inflammatory, and satiety-inducing activities. Marine organisms, in particular, are gaining attention due to the bioactivity and novelty of their peptides.

- **Plant Proteins**: Legumes (e.g., soy, lentils, chickpeas) and cereals (e.g., wheat, rice, oats) are valuable plant-based sources of bioactive peptides. These plant proteins are abundant, sustainable, and often rich in peptides with antioxidant, antihypertensive, and hypocholesterolemic effects. Moreover, they align with the growing demand for plant-based nutrition.

- **Byproducts and Waste Streams**: The valorization of food industry byproducts such as whey permeate, fish skin, scales, bones, and oilseed meals represents a cost-effective and environmentally sustainable approach. These underutilized protein sources can be enzymatically hydrolyzed to generate peptides with promising bioactivities, contributing to circular bioeconomy models.

2.2 Methods of Extraction and Production

The generation of bioactive peptides involves the cleavage of parent proteins using various hydrolytic methods [9]. The choice of method depends on the source material, desired peptide activity, and scale of production. Common extraction approaches include:

- **Enzymatic Hydrolysis**: This is the most widely used method for producing bioactive peptides. It involves the use of specific proteolytic enzymes (e.g., trypsin, pepsin, alcalase, papain) to cleave proteins under controlled pH and temperature conditions. The hydrolysate is then subjected to separation and purification steps such as ultrafiltration and chromatography.

- **Fermentation**: Lactic acid bacteria and other microbial strains can naturally hydrolyze proteins during fermentation processes, releasing bioactive peptides. This method is widely used in the production of fermented dairy and soy products and is favored for its mild processing conditions and natural appeal.

- **Chemical Hydrolysis**: Although effective, chemical hydrolysis using acids or bases is less preferred due to the risk of peptide degradation, toxicity, and lack of specificity.

- **Novel Techniques**: Emerging technologies such as high-pressure processing, ultrasound-assisted hydrolysis, and pulsed electric fields are being explored to enhance peptide yield, maintain bioactivity, and improve efficiency in large-scale applications.

After hydrolysis, peptide fractions are typically purified using techniques like ultrafiltration, reverse-phase high-performance liquid chromatography (RP-HPLC), or ion-exchange chromatography [10]. Advanced analytical tools such as mass spectrometry (MS) and nuclear magnetic resonance (NMR) are employed for peptide identification and characterization.

Table 1. Major Food Sources of Bioactive Peptides and Their Applications

Source	Protein Type	Examples of Peptides	Bioactivity	Industrial Application
Dairy (milk, whey)	Casein, whey proteins	IPP, VPP	Antihypertensive, antioxidant	Yogurt, infant formula, supplements
Fish and seafood	Collagen, myofibrillar	Collagen peptides	Antioxidant, skin health, antimicrobial	Nutraceuticals, cosmeceuticals
Soybean	Glycinin, β-conglycinin	Lunasin	Anticancer, cholesterol-lowering	Protein bars, beverages
Egg	Ovalbumin, lysozyme	IRW, IQW	Anti-inflammatory, antihypertensive	Supplements, functional snacks
Legumes & cereals	Gluten, albumins	Various di-/tri-peptides	Antioxidant, hypoglycemic	Bakery, protein shakes
Byproducts (e.g., fish skin, whey waste)	Collagen, casein derivatives	Collagen hydrolysates	Joint health, wound healing	Biopharmaceuticals, waste valorization

Table 2. Biological Activities of Selected Bioactive Peptides

Peptide Name	Sequence	Source Protein	Primary Activity	Mechanism of Action
IPP	Ile-Pro-Pro	Casein	Antihypertensive	ACE inhibition
VPP	Val-Pro-Pro	Casein	Antihypertensive	ACE inhibition
Lunasin	43-aa peptide	Soybean	Anticancer, anti-inflammatory	Histone deacetylase inhibition
IRW	Ile-Arg-Trp	Egg white	Anti-inflammatory	Inhibits NF-κB and endothelial inflammation
KLF	Lys-Leu-Phe	Fish collagen	Antioxidant	Scavenges free radicals
YW	Tyr-Trp	Wheat gluten	Antioxidant	Metal ion chelation, ROS scavenging

Table 3. Challenges and Solutions in Bioactive Peptide Commercialization

Challenge	Description	Potential Solution
Low stability during digestion	Peptides degraded by GI enzymes	Microencapsulation, carrier systems
Poor sensory attributes	Some peptides impart bitterness or off-flavors	Enzymatic modification, masking agents
Batch-to-batch variability	Variations in raw materials or hydrolysis methods	Standardized production protocols and quality control
Regulatory approval	Need for evidence-based health claims	Clinical trials, toxicology testing, EFSA/FDA validation
Cost of purification and formulation	High cost of isolating and stabilizing bioactive peptides	Use of food waste/byproducts, cost-effective technologies

3. Health Benefits of Bioactive Peptides

Bioactive peptides exert a broad spectrum of biological activities, positioning them as multifunctional agents in the prevention and management of various chronic and metabolic diseases. Their efficacy is closely linked to their amino acid composition and sequence, molecular size, and structural conformation [11]. The mechanisms of action vary widely and often involve interactions with cellular receptors, enzymes, or microbial membranes. The following sections elaborate on the key physiological benefits of food-derived bioactive peptides.

3.1 Antihypertensive Activity

One of the most widely studied functions of bioactive peptides is their antihypertensive effect, primarily through inhibition of angiotensin-I converting enzyme (ACE), a key regulator in the renin-angiotensin system responsible for blood pressure control. By inhibiting ACE, these peptides prevent the conversion of angiotensin I to angiotensin II, a potent vasoconstrictor, thereby reducing vascular resistance and lowering blood pressure [12]. Notable peptides such as IPP (Isoleucine–Proline–Proline) and VPP (Valine–Proline–Proline), isolated from fermented milk products, have demonstrated clinically validated antihypertensive effects in both animal models and human trials. These peptides are particularly promising as natural alternatives to synthetic ACE inhibitors, which often have undesirable side effects.

3.2 Antioxidant Properties

Oxidative stress is a major contributing factor in aging and the pathogenesis of chronic diseases such as cancer, cardiovascular disease, and neurodegenerative disorders. Bioactive peptides with antioxidant properties mitigate oxidative stress by scavenging reactive oxygen species (ROS), chelating pro-oxidative metal ions, and upregulating endogenous antioxidant enzymes [13]. These peptides often contain amino acids like histidine, tyrosine, tryptophan, methionine, and cysteine, which donate hydrogen atoms or electrons to neutralize free radicals. Antioxidant peptides derived from sources such as soy, egg, and marine proteins have shown potential in extending shelf life and enhancing the nutritional value of functional foods.

3.3 Antimicrobial Effects

Antimicrobial peptides (AMPs) represent a critical class of bioactives with the ability to inhibit or kill a wide range of pathogenic microorganisms, including bacteria, fungi, and viruses. These peptides typically exert their effects by disrupting microbial membranes, forming pores, or inhibiting essential metabolic pathways [14]. Food-derived AMPs such as lactoferricin (from milk) and lysozyme-derived fragments (from egg white) are being explored as natural food preservatives to enhance safety and shelf life. Additionally, AMPs are being evaluated for therapeutic applications to combat antibiotic-resistant strains, offering a promising alternative to conventional antimicrobials.

3.4 Antidiabetic and Hypocholesterolemic Effects

Bioactive peptides have demonstrated multiple mechanisms in managing metabolic disorders such as type 2 diabetes and hypercholesterolemia. Peptides that inhibit dipeptidyl peptidase-IV (DPP-IV) can enhance incretin activity, improve insulin secretion, and regulate blood glucose levels. Other peptides act by mimicking insulin or enhancing glucose transporter expression [15]. In the context of cholesterol metabolism, some peptides inhibit the intestinal absorption of cholesterol by interfering with micelle formation, while others enhance hepatic cholesterol excretion through bile acid synthesis. Peptides derived from soy, oat, and fish proteins have shown lipid-lowering properties in both in vitro and in vivo studies.

3.5 Immunomodulatory and Anti-inflammatory Effects

The immunomodulatory potential of bioactive peptides is gaining recognition for its relevance in managing autoimmune diseases, allergies, and chronic inflammation. These peptides can stimulate or suppress immune cell activity, regulate cytokine production, and enhance phagocytic capacity [16]. Examples include casein-derived peptides that stimulate lymphocyte proliferation and soy-derived peptides that modulate macrophage activity. Anti-inflammatory effects are often mediated through the downregulation of pro-inflammatory cytokines (e.g., TNF-α, IL-6) and upregulation of anti-inflammatory mediators. Such properties make these peptides attractive candidates for nutraceuticals targeting immune health and inflammatory diseases.

4. Applications in the Food and Pharmaceutical Industries

Bioactive peptides are increasingly incorporated into functional foods, nutraceuticals, and therapeutic products.

4.1 Functional Foods and Beverages

Peptides are added to yogurts, protein bars, infant formula, and sports drinks to provide added health benefits. Peptide-rich hydrolysates can improve texture and flavor while enhancing nutritional profiles.

4.2 Dietary Supplements

Many commercial supplements contain purified or semi-purified peptide preparations aimed at cardiovascular health, immune support, or sports recovery [17].

4.3 Pharmaceuticals and Cosmeceuticals

Peptides with high bioactivity and stability are being formulated into therapeutic agents, especially for cardiovascular and metabolic disorders [18]. Some peptides are also used in skincare for their anti-aging and anti-inflammatory properties.

5. Challenges in Commercialization

The potential of bioactive peptides, several barriers must be overcome:

- **Stability and Bioavailability**: Peptides can be degraded in the gastrointestinal tract before reaching target sites.
- **Standardization**: Variability in raw materials and hydrolysis conditions makes reproducibility challenging.
- **Regulatory Approval**: Health claims must be validated through clinical trials, requiring time and resources.
- **Taste and Solubility**: Some hydrolysates have bitter flavors and poor solubility, affecting consumer acceptance [19-21].

6. Future Prospects

The future of bioactive peptides is promising, driven by technological and scientific advances:

- **Peptidomics and Bioinformatics**: These tools allow identification of novel peptides and prediction of their activity using in silico methods.
- **Encapsulation Technologies**: Liposomes and nanoemulsions are being developed to enhance peptide delivery and stability.
- **Sustainable Sourcing**: Food industry byproducts are increasingly explored as cost-effective peptide sources, supporting a circular bioeconomy.
- **Precision Nutrition**: Personalized diets incorporating specific peptides based on individual health profiles may become a key strategy in preventive medicine.

7. Conclusion

Bioactive peptides derived from food proteins represent a promising class of functional ingredients that offer a safe, natural, and effective approach to promoting health and managing chronic diseases. Their diverse biological activities—including antihypertensive, antioxidant, antimicrobial, antidiabetic, and immunomodulatory effects—highlight their significant therapeutic potential. As consumer demand grows for health-enhancing foods and natural remedies, bioactive peptides are increasingly positioned at the intersection of nutrition, medicine, and biotechnology. The existing challenges—such as issues related to stability, bioavailability, standardization, and regulatory hurdles—the progress in enzymatic hydrolysis techniques, peptide characterization, and delivery systems is paving the way for broader commercial application. Moreover, the integration of advanced tools such as bioinformatics, peptidomics, and precision nutrition platforms is accelerating the discovery and development of novel peptides with targeted physiological effects, sustainable sourcing from food processing byproducts, along with interdisciplinary collaboration between food scientists, biotechnologists, and healthcare professionals, will be crucial for fully realizing the potential of bioactive peptides. Their application across food, pharmaceutical, and cosmeceutical industries not only enhances product functionality but also contributes to the development of personalized and preventive health strategies. As such, bioactive peptides stand as a cornerstone in the future of functional foods and evidence-based nutrition.

References

1. Zaky, A. A., Simal-Gandara, J., Eun, J. B., Shim, J. H., & Abd El-Aty, A. M. (2022). Bioactivities, applications, safety, and health benefits of bioactive peptides from food and by-products: A review. *Frontiers in Nutrition*, *8*, 815640.

2. Udenigwe, C. C., & Aluko, R. E. (2012). Food protein-derived bioactive peptides: production, processing, and potential health benefits. *Journal of food science*, *77*(1), R11-R24.

3. Peighambardoust, S. H., Karami, Z., Pateiro, M., & Lorenzo, J. M. (2021). A review on health-promoting, biological, and functional aspects of bioactive peptides in food applications. *Biomolecules*, *11*(5), 631.

4. Kadam, S. U., Tiwari, B. K., Álvarez, C., & O'Donnell, C. P. (2015). Ultrasound applications for the extraction, identification and delivery of food proteins and bioactive peptides. *Trends in Food Science & Technology*, *46*(1), 60-67.

5. López-Pedrouso, M., Zaky, A. A., Lorenzo, J. M., Camina, M., & Franco, D. (2023). A review on bioactive peptides derived from meat and by-products: Extraction methods, biological activities, applications and limitations. *Meat Science*, *204*, 109278.

6. Yuan, H., Luo, Z., Ban, Z., Reiter, R. J., Ma, Q., Liang, Z., ... & Li, L. (2022). Bioactive peptides of plant origin: distribution, functionality, and evidence of benefits in food and health. *Food & Function*, *13*(6), 3133-3158.

7. Kitts, D. D., & Weiler, K. (2003). Bioactive proteins and peptides from food sources. Applications of bioprocesses used in isolation and recovery. *Current pharmaceutical design*, *9*(16), 1309-1323.

8. Sánchez, A., & Vázquez, A. (2017). Bioactive peptides: A review. *Food quality and safety*, *1*(1), 29-46.

9. Jia, L., Wang, L., Liu, C., Liang, Y., & Lin, Q. (2021). Bioactive peptides from foods: production, function, and application. *Food & Function*, *12*(16), 7108-7125.

10. Puri, M. (Ed.). (2017). *Food bioactives: extraction and biotechnology applications*. Springer.

11. Korhonen, H., & Pihlanto, A. (2006). Bioactive peptides: production and functionality. *International dairy journal*, *16*(9), 945-960.

12. Ovando, C. A., Carvalho, J. C. D., Vinícius de Melo Pereira, G., Jacques, P., Soccol, V. T., & Soccol, C. R. (2018). Functional properties and health benefits of bioactive peptides derived from Spirulina: A review. *Food reviews international*, *34*(1), 34-51.

13. Hayes, M. (2018). Food proteins and bioactive peptides: New and novel sources, characterisation strategies and applications. *Foods*, *7*(3), 38.

14. Chakrabarti, S., Guha, S., & Majumder, K. (2018). Food-derived bioactive peptides in human health: Challenges and opportunities. *Nutrients*, *10*(11), 1738.

15. Singh, B. P., Bangar, S. P., Alblooshi, M., Ajayi, F. F., Mudgil, P., & Maqsood, S. (2023). Plant-derived proteins as a sustainable source of bioactive peptides: recent research updates on emerging production methods, bioactivities, and potential application. *Critical reviews in food science and nutrition*, *63*(28), 9539-9560.

16. Hajfathalian, M., Ghelichi, S., García-Moreno, P. J., Moltke Sørensen, A. D., & Jacobsen, C. (2018). Peptides: Production, bioactivity, functionality, and applications. *Critical reviews in food science and nutrition*, *58*(18), 3097-3129.

17. Boonlao, N., Mala, T., Koirala, S., & Anal, A. K. (2022). Bioactive Proteins and Peptides from Agro-Industrial Waste: Extraction and Their Industrial Applications. In *Valorization of Agro-Industrial Byproducts* (pp. 117-142). CRC Press.

18. Murtaza, Mian Anjum, Shafeeqa Irfan, Iram Hafiz, Muhammad Modassar AN Ranjha, Abdul Rahaman, Mian Shamas Murtaza, Salam A. Ibrahim, and Shahida Anusha Siddiqui. "Conventional and novel technologies in the production of dairy bioactive peptides." *Frontiers in Nutrition* 9 (2022): 780151.

19. López-Barrios, L., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2014). Bioactive peptides and hydrolysates from pulses and their potential use as functional ingredients. *Journal of food science*, *79*(3), R273-R283.

20. Chew, L. Y., Toh, G. T., & Ismail, A. (2019). Application of proteases for the production of bioactive peptides. In *Enzymes in food biotechnology* (pp. 247-261). Academic Press.

21. Lorenzo, J. M., Munekata, P. E., Gomez, B., Barba, F. J., Mora, L., Perez-Santaescolastica, C., & Toldra, F. (2018). Bioactive peptides as natural antioxidants in food products–A review. *Trends in food science & technology*, *79*, 136-147.