Microbial Fermentation for the Production of Rapeseed Protein Peptides

Rapeseed meal is the primary byproduct of rapeseed oil extraction, with enormous annual production in China, representing a plant protein resource with significant potential. Rapeseed protein boasts a balanced amino acid profile and high nutritional value. However, traditional rapeseed meal contains antinutritional factors such as glucosinolates, phytate, and tannins, coupled with poor protein solubility, flavor, and functional properties, limiting its direct high-value application in the food sector. In recent years, converting rapeseed meal through microbial fermentation to produce bioactive peptides and functional protein components has emerged as a key research direction for enhancing its value and achieving resource recycling. This paper aims to review the process principles, key technologies, functional characteristics, and application prospects of producing rapeseed protein peptides via microbial fermentation.

I. Characteristics and Pretreatment of Rapeseed Meal as a Fermentation Substrate

Rapeseed meal is one of the ideal substrates for microbial fermentation, but its inherent limitations must be addressed.

1. Nutritional Composition and Limiting Factors

Rich protein resource: Defatted rapeseed meal contains 35%-45% protein, serving as an excellent nitrogen source for microbial growth and enzyme production, as well as a direct precursor for peptide synthesis.

Antinutritional Factors: Primary limitations include glucosinolates, phytate, sinigrin, and tannins. These substances not only affect product palatability and safety but may also inhibit microbial growth and metabolic activity.

Dense Fiber Structure: Cellulose and hemicellulose in rapeseed meal encapsulate proteins, impairing microbial and enzymatic accessibility to these proteins.

2. Essential Raw Material Pretreatment

To enhance fermentation efficiency, rapeseed meal is commonly pretreated:

Grinding: Increases specific surface area, facilitating microbial attachment and nutrient release.

Detoxification: Methods such as wet-heat treatment, microwave irradiation, or solvent extraction reduce harmful substances like glucosinolates. In modern solid-state fermentation processes, specific microbial strains are often selected to simultaneously degrade these antinutrients during fermentation, achieving “biological detoxification.”

II. Core Principles and Advantages of Microbial Fermentation Methods

Microbial fermentation for rapeseed peptide production primarily relies on the abundant protease systems secreted by microorganisms during growth. These enzymes hydrolyze rapeseed protein into small-molecule peptides and amino acids, accompanied by a series of beneficial biochemical transformations.

1. Primary Mechanisms of Action

Enzymatic Protein Hydrolysis: Endopeptidases and exopeptidases secreted by fermentation strains (e.g., Bacillus, Aspergillus, Lactobacillus) synergistically cleave macromolecular proteins into short-chain peptides and free amino acids.

Biological Detoxification: Certain strains produce enzymes like myrosinase, phytase, and tanninase to degrade corresponding antinutritional factors, enhancing product safety.

Flavor Improvement: Microbial metabolism generates flavor compounds such as organic acids and esters, masking or transforming inherent undesirable flavors (e.g., bitterness, pungency) in rapeseed protein to improve product palatability.

Synthesis of New Compounds: Beneficial metabolites like vitamins, antimicrobial substances, and functional polysaccharides may emerge during fermentation, forming multifunctional systems with peptides.

2. Advantages Over Traditional Enzymatic Methods

Lower Cost: Direct microbial enzyme production eliminates expenses associated with commercial enzyme preparation, purification, and addition.

Rich and synergistic enzyme systems: Microbial protease systems are often more complex and diverse, potentially yielding peptide mixtures with enhanced biological activity.

Simultaneous multifunctional processing: Concurrently achieves detoxification, flavor enhancement, and nutritional fortification during peptide production, enabling high process integration.

Mild and environmentally friendly conditions: Typically conducted at mesophilic temperatures and atmospheric pressure with low energy consumption, qualifying as a green bioprocessing technology.

III. Key Influencing Factors in Fermentation Processes

The quality and yield of fermentation products are jointly influenced by the microbial strains, process parameters, and fermentation mode.

1. Selection and Combination of Fermentation Strains

Microbial strains are the core. Commonly used strains include:

Bacillus species: Such as Bacillus subtilis and Bacillus licheniformis, which possess strong protease production capabilities and rapid growth, serving as primary industrial strains for peptide production.

Aspergillus species: Such as Aspergillus oryzae and Aspergillus niger, which not only produce proteases but also cellulases and phytase, aiding substrate degradation and detoxification.

Lactic acid bacteria: Such as Lactobacillus plantarum, which enhances flavor, produces organic acids, inhibits contaminating microorganisms, and is suitable for mixed-microorganism fermentation.

Yeast: Used to enhance nutritional value and flavor.

Mixed-microorganism fermentation represents the current optimization trend. By rationally combining different strains and leveraging their metabolic complementarity, superior comprehensive effects in detoxification, peptide production, and flavor development can be achieved compared to single-microorganism fermentation.

2. Key Process Parameter Control

Substrate Composition and Moisture: An appropriate carbon-to-nitrogen ratio supports microbial growth and enzyme production. In solid-state fermentation, water activity is the decisive factor, typically controlled between 40%–60%.

Temperature and pH: Different strains have optimal growth and enzyme production temperatures (often 30–37°C) and initial pH levels (neutral or slightly alkaline). pH dynamically changes during fermentation.

Fermentation Duration: Requires balancing protease yield, protein hydrolysis degree, and target peptide molecular weight distribution. Insufficient time leads to incomplete hydrolysis; excessive time may over-hydrolyze peptides into amino acids, reducing active peptide yield.

Aeration and Agitation: Adequate oxygen supply is critical for aerobic bacteria in both solid-state and liquid fermentation.

3. Fermentation Modes

Solid-State Fermentation: Rapeseed meal serves as the solid substrate inoculated with microbial strains. This method features simple equipment, low energy consumption, minimal wastewater, and better mimics natural fermentation processes, making it the current mainstream approach in research and application.

Liquid Fermentation: Rapeseed meal is extracted or made into a suspension for fermentation. It offers good mass and heat transfer, facilitates automated control, but incurs high separation costs later and may generate significant wastewater.

IV. Functional Characteristics and Applications of Fermentation Products

Microbial fermentation significantly enhances the functional properties of rapeseed protein products, expanding their application scope.

1. Enhanced Functional Properties

Solubility and Foaming/Emulsifying Properties: Enzymatic hydrolysis reduces protein molecular size and exposes hydrophilic groups, substantially improving solubility at acidic or neutral pH. This enhances foaming capacity and emulsion stability.

Antioxidant Activity: Fermentation-derived peptides, rich in hydrophobic amino acids and hydrogen-donating residues, exhibit potent free radical scavenging and metal ion chelation capabilities.

ACE Inhibition Activity: Studies have identified short peptides with angiotensin-converting enzyme (ACE) inhibitory activity in fermented rapeseed meal, suggesting potential adjunctive antihypertensive effects.

Antimicrobial and Immunomodulatory Activity: Active peptides found in certain fermentation products may exhibit antimicrobial or immune-enhancing potential.

2. Primary Application Directions

Functional Food Ingredients: As a high-quality protein source and functional factor, added to nutrition bars, beverages, and special dietary foods.

Animal Feed Additives: Fermented rapeseed peptide products offer excellent palatability, high digestibility, and low levels of antinutritional factors, making them an ideal protein source for premium aquatic and livestock feeds.

Bioactive Peptide Raw Materials: Further isolation and purification of antioxidant peptides, antihypertensive peptides, etc., for use in health food or cosmetic development.

Plant-Based Fermented Seasonings: Utilizing their flavor compounds and taste-enhancing peptides to develop novel seasoning bases.

V. Challenges and Future Outlook

1. Key Challenges Currently Faced

Process Standardization and Stability: Solid-state fermentation involves relatively complex process control. Achieving batch-to-batch consistency in product activity and quality at industrial scale is critical.

Precise Identification of Bioactive Peptides: Fermentation products are complex mixtures of peptides. Efficiently identifying the structures of key bioactive peptide segments and elucidating their structure-activity relationships requires further research.

Production Cost-Benefit Balance: While enzyme costs are eliminated, fermentation cycles are lengthy, and energy consumption in downstream separation and drying processes requires optimization.

Safety and Regulatory Compliance: Comprehensive safety assessments of microbial residues and metabolites in final fermentation products are essential, along with establishing corresponding product standards.

2. Future Development Trends

Engineered Strain Construction: Utilize metabolic engineering and synthetic biology techniques to modify microorganisms, enhancing expression of target proteases and detoxifying enzymes, or design “cell factories” for synthesizing specific functional peptides.

Intelligent Fermentation and Control: Integrate sensor technology and artificial intelligence to achieve online monitoring and adaptive precision control of key fermentation parameters (e.g., pH, humidity, biomass).

Multi-omics Applications: Utilizing metagenomics, metabolomics, and related technologies to decipher the relationships between microbial community succession, metabolic pathways, and product formation during fermentation, thereby guiding process optimization.

High-Value Product Development: Promoting the application of fermented rapeseed peptides in higher-value-added fields such as specialized medical foods, sports nutrition, and precision nutrition.

VI.Conclusion

Microbial fermentation technology has pioneered an efficient and eco-friendly pathway for the high-value utilization of rapeseed meal, a major agricultural byproduct. It not only serves as an effective means to convert proteins into easily absorbable, multifunctional bioactive peptides but also represents a comprehensive bioprocessing approach that simultaneously achieves detoxification, modification, and nutritional fortification. Although challenges remain in industrialization—including process control, cost optimization, and standardization—advances in biotechnology and food science, coupled with ongoing efforts in strain selection, process refinement, and product innovation, position microbial fermentation-derived rapeseed protein peptides to become a key novel functional protein source for food, feed, and health industries. This approach fully realizes the resource value across the entire rapeseed value chain, holding significant implications for promoting sustainable agricultural development and public health.