Research on Processing Technology and Quality Control of Plant-based Artificial Meat

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Abstract. With the continuous growth of the global population, the demand for meat products is also increasing, and the consumption of traditional meat products is increasing, accompanied by increasing emphasis on dietary health, all of which further exacerbates the pressure on resources and the environment. Plant-based meat alternatives, as a new type of food that can replace traditional meat products, the development and progress of its technology are expected to solve these problems. This paper mainly systematically reviewed the protein modification technology and fiber structure simulation technology and simply showed the research status and prospect of plant-based meat processing technology through of the relevant principles of the three physical and chemical modification technologies and 3D printing technology. In addition, this paper also systematically introduces the technical process to improve the chewiness and juiciness of artificial meat products, such as adjusting extrusion parameters and speed, adding plant oil microcapsules and so on. In this paper, through the discussion of the processing technology of artificial meat and quality control research, it is expected to provide reference ideas for the future research direction and scale development path of the relevant fields.

Keywords: Artificial meat, protein modification, 3D printing, microencapsulation.

1. Introduction

With the growth of the global population, increasing environmental and resource pressures, and the gradual improvement of consumers' health consciousness about diet, plant-based meat, as new sustainable food, is attracting widespread attention from society. A thriving plant-based food industry has emerged to meet consumer demand and support dietary shift towards plant-based eating. ‘Traditional’ plant-based diets are low-energy density, nutrient dense, low in saturated fat and purportedly associated with health benefits [1]. According to the United Nations statistical data, global meat consumption is directly proportional to the population, and by 2022 it has exceeded 300 million tons. According to the United Nations Food and Agriculture Organization, global meat demand is expected to reach 455 million tons by 2050. Compared with traditional animal-sourced meat products, plant-based imitation meat shows significant advantages in reducing greenhouse gas emissions, saving water resources and reducing land use [2].

In recent years, important breakthroughs have been made in the key fields of artificial meat research, such as the modification of plant protein raw materials, the restructuring technology of, and the flavor regulation system. In terms of the processing technology of artificial meat, extrusion fissurization technology has become the mainstream processing method by applying high temperature and high pressure to promote plant protein to form fibrous structures similar to meat. On the other hand, the construction strategy of protein networks based on the molecular interaction mechanism, and the development and application of flavor precursor substances such as plant-derived me, significantly improved the sensory quality of products [3]. Plant-based meat alternatives have broad prospects, but there are still technical difficulties such as loose texture and lack of flavor at present, which will directly affect consumers and the scale of industrial development [4]. Therefore, solving these problems not only helps meet consumer demand for healthy and environmentally friendly food but also can promote the food industry to take a big step towards sustainability.

This paper will systematically review the innovative progress of plant-based cultured meat technology, the core of which is to simulate the characteristics of animal meat through multiprocessing means. In the future, breakthroughs need to be achieved in the precise regulation of fiber structure, naturalization of flavor, and cost control. With the power of interdisciplinary, the entire industry will be pushed towards high-quality development.

2. Processing Technology of Plant-based Imitation Meat

2.1. Protein Modification Technology

Plant protein modification technology mainly involves treating plant proteins through methods such as physical, chemical, and biological modification to alter their molecular structure or chemical groups, thereby enhancing related functional properties of the proteins. Firstly, physical modification induces conformational changes in proteins by energy input or mechanical action, mainly involving the rearrangement of non-covalent bonds such as bonds and hydrophobic interactions, without changing the primary structure of proteins. This process can lead to the partial unfolding or a change in the aggregated state of proteins, thus regulating their functional properties. Chemical modification, on the other hand, changes the chemical properties of amino acid side chains through covalent modification, involving reactions such as nucleophilic, oxidation-reduction, etc., with the modification sites usually being active groups such as cysteine sulfhydryl groups. Moreover, biological modification is to achieve precise modification of protein structure by using the specific catalytic action of enzyme or microbial metabolism, which has high substrate specificity mild reaction. The Table 1 is a classification table of plant protein modification technologies.

Table 1. Classification Table of Plant Protein Modification Technology [5]

Modified method	Handling method	Modification principle	Functional properties
Physical modification	Heat treatment	Mainly based on the influence of high temperature on the internal structure and interaction forces of protein molecules.	The hydrogen bond of protein is destroyed, hydrophobic groups are exposed, and the solubility and thermal stability of protein are changed.
	Extrusion treatment	Under high temperature, high pressure and high shear, proteins undergo hydrolysis and denaturation.	Altering the intermolecular interactions of proteins, solubility is improved.
	Pulsed electric field	The polar groups of proteins absorb energy to produce free radicals, which promote the aggregation or unfolding of proteins.	The hydrophobicity and emulsifying properties of the protein were improved, and the thiol content of the protein was increased.
	High pressure treatment	The surface charge distribution of the protein is altered, increasing the degree of protein aggregation, forming helical curling, and chemical bonds change.	Improved the thermal stability of proteins and the stability of emulsions.
	Ultrasonic	Based on the cavitation effect and mechanical effect of ultrasound, the molecular structure of proteins is affected, and the intermolecular forces are destroyed.	The hydrophobicity of protein surface was increased, the particle size was decreased, and the emulsifying properties were improved.
	Irradiation	The use of high-energy radiation to penetrate matter and interact with the atoms and molecules within it, breaking the chemical bonds within proteins and causing changes in protein conformation	Reduce the allergenicity of protein, change the emulsifying properties, and improve the emulsifying activity.
Chemical modification	Acid treatment	The hydrolysis of protein molecules under weak acid conditions is mainly achieved by increasing the number of hydrophobic groups on the protein surface.	Improve the solubility, emulsifying and foaming properties of proteins, etc.
	Alkali treatment	Under certain pH conditions, the peptide bonds of protein molecules break, the polar groups of proteins are exposed, and cross-linking reactions occur	Improve the emulsification and solubility of protein in water.
	Phosphorylation	Add phosphorylation reagents to modify the protein, changing the isoelectric point of the protein.	Improve the solubility of protein, enhance the emulsifying ability and water retention of protein.
	Acylation	The process of introducing an acyl group by reacting acylating agents (succinic anhydride, acetic anhydride) with nucleophilic in protein molecules to form amide or ester bonds.	Altering the hydrophobicity and hydrophilicity of proteins, affecting their emulsifying, stability, and solubility.
	Glycosylation	Sugars undergo the Maillard reaction with proteins to generate glycated proteins.	Improve the thermal stability of proteins, and enhance their solubility, water retention, oil retention, etc.
Bio modification	Enzyme modification	Protein interacts with enzyme, protein is cross-linked and hydrolyzed, conformation is changed.	Improve the emulsifying, gelling, antioxidant properties of protein, etc.

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2.2. Fiber Structure Simulation Technology

In the R&D of plant-based artificial meat, fiber structure simulation technology is crucial in shaping the lifelike texture of the product. 3D printing technology is based on a plant protein-polysaccharide composite system, where plant protein provides the main nutrients and structural support, and polyamides work synergistically with protein due to their excellent gelling and bonding properties [6]. During the printing process, the movement of the nozzle is precisely controlled by a computer program, and the mixed materials are deposited layer by layer, so that each of materials is cured under specific conditions, gradually constructing a fiber network with a porous structure. From the perspective of the microstructure of food, this structure is similar to the arrangement of muscle bundles, thus being able to endow the product with a multilevel texture and suitable porosity, making its appearance and taste closer to real meat, greatly enhancing the bionic effect of the product. Compared with 3D printing technology, traditional processes usually have problems such as a large amount of raw material rejection and material consumption in mold making. With the in-depth research and development of various fiber simulation technologies, 3D printing technology will break the standardization limitations of traditional food processing technology, making-scale personalized custom production possible. Therefore, this is also the development direction that the future consumer market expects and is moving towards [7].

2.3. Future Development Direction

The reduction of the production cost and the realization of the scaling-up of plant-based cultured meat need to be promoted by the multi-dimensional synergy progress of technology iteration, raw material optimization and production process integration.

2.3.1. Optimization of Processing Technology Energy Efficiency

High moisture extrusion (HME) and 3D bio printing technologies occupy 30-45% of the manufacturing cost in the process of plant-based artificial meat, so it should be necessary to reduce its energy consumption by process parameters in the future production planning. In recent years, domestic research has already achieved the purpose of optimizing the process and partially reducing consumption through a variety of ways, such as the collaborative optimization of screw and speed, and the collaborative control of temperature and shear force [8]. In the subsequent research and development of plant-based artificial meat, the optimization of processing technology is still one of the most important parts to reduce energy consumption. Therefore, in the future, when studying related fields in depth, it is also necessary to focus on the optimization of processing technology energy efficiency, thereby reducing production costs and promotion and innovation.

2.3.2. System Engineering Innovation For Mass Production

The core of large-scale production of plant-based meat lies in the reconstruction of production processes, the upgrading of automation, and the synergy of the industrial, which requires breakthroughs in efficiency through modular design, continuous manufacturing, and intelligent management. On one hand, it can be realized by modularized line design and flexible manufacturing, such as container type micro-factory (Micro-factory) and reconfirm manufacturing system (RMS) [9]. On the other hand, it can also optimize its continuous production process and access a variety of intelligent management and control technologies, thus breaking through the bottleneck of traditional segment production and achieving a seamless transition from raw materials to finished products.

3. Research on Quality Control of Plant-based Artificial Meat

3.1. Hardness and Elasticity Modulation

Texture profile is a key indicator to measure the quality of plant-based meat analogues, and it also directly affects the consumer's eating experience, so optimizing is an important measure to enhance the market competitiveness of the product. The hardness and elasticity of plant-based imitation meat greatly depend on the degree of protein crosslinking, which can be achieved by adjusting the extrusion parameters. During the extrusion process, temperature control plays a crucial role. Raising the temperature can accelerate the thermal motion of protein molecules, enhancing the interactions between protein molecules which in turn increases the degree of crosslinking and improves the hardness of the product [10]. However, excessively high temperatures can cause protein denaturation, resulting in a product that too hard and loses its elasticity.

In addition, the screw speed is also not to be neglected, it determines the residence time of the material in the extruder and the magnitude of the shear force it subjected to. Higher screw speed increases shear force, making protein molecules more likely to orient and crosslink, which helps improve elasticity; to slow a speed may result in uneven linking, affecting product quality [11]. By precisely controlling the temperature and the screw speed, the protein crosslinking degree can reach an ideal state, which endows the product with hardness and elasticity to that of real meat, meeting the consumer's need for chewiness.

3.2. Juiciness Enhanced

Juiciness is an important factor to make plant-based imitation meat more realistic, and adding plant oil microcapsules is one of the effective methods to juiciness. Microcapsules are a technology in which a uniform or heterogeneous matrix is wrapped on the surface of tiny particles or droplets to form small capsules in a liquid or state [12], while plant oil microcapsules refer to the tiny particles formed by wrapping plant oil in a wall material. During chewing, the microcapsules break and release the oil, simulating the fat and juicy taste of meat, and the oil can also carry flavor substances, further enrich the taste of the product. In addition, the use of hydrophilic gels such as carrageenan is also essential, as it has a powerful water absorption and swelling capacity, which form a three-dimensional network structure in the plant-based artificial meat system, locking in moisture firmly [13]. When the consumer chews, this trapped moisture is then slowly released, creating a juicy eating experience that effectively improves the dry texture of the product and enhances its overall.

4. Conclusion

Plant-based meat alternatives, as innovative products to address resource and environmental pressures and meet consumer health needs, are of great significance in today's era. Through the research on key processing technologies, such as protein modification technology, fiber structure simulation technology and so on, the following research can further understand the various core elements shape product quality. In terms of quality control, from the optimization of qualitative characteristics, flavor enhancement, nutritional balance design to safety control, each link is closely linked, and they all the market acceptance of products. Despite the problems of insufficient structural authenticity and excessive cost of plant-based cultured meat at present, the development directions of multi-technologies synergy, production and sustainable raw material development provide possibilities for it to break through difficulties and achieve high-quality development. In the future, people still need to deepen interdisciplinary research, so as to solve key problems such as precise regulation of fiber structure, naturalization of and cost control of plant-based artificial meat. Advancing the plant-based meat industry will be beneficial to the goal of human health and sustainable development, and will contribute to alleviation of resource pressure.

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