Dean&Francis
ISSN 2959-409X

Research on the Balancing Effect of Standardized Production of Plant Protein Hydrolysates on the Cost and Quality of Cultured Meat

Siying Chen[1],

Yibo Chen[2],

Xuemeng Guo[3]

and Zeye Wang[4, *]

[1]Creative Secondary School, Hong Kong Special Administrative Region, China
[2]College of Food Science, Northeast Agricultural University, Harbin, 150030, China
[3]Xi'an Tie Yi International Curriculum Center, Xi'an, 710000, China
[4]College of Agriculture, Yanbian University, Yanji, 133002, China
*Corresponding author: w7415926@gmail.com

Abstract:

To address the insufficient sustainability of traditional animal husbandry and the issues of high costs and difficult quality control in the cultivated meat industrialization process, this study explores the impact of standardized production of plant protein hydrolysates (PPH) on balancing the cost and quality of cultivated meat. Through systematic review and analysis, it is found that the high cost of cultivated meat mainly stems from the expenses of culture medium, labor, and equipment, while the shortage of serum substitutes further exacerbates this bottleneck. In terms of quality, cultivated meat needs to match traditional meat in terms of texture, sensory properties, and nutrition. Currently, non-standardized PPH has unstable compositions due to random raw material sources, which in turn affects its application effects. This study aims to fill the research gap between PPH technology and the "cost-quality" relationship of cultivated meat and provide a standardized serum replacement solution for industrialization. In the future, in-depth research should be conducted in combination with technologies such as 3D scaffolds.

Keywords: Cultured Meat; Plant Protein Hydrolysates; Balancing Effect.

1. Introduction

It is projected that the global population will reach 9.7 billion by 2050. The problems of greenhouse gas emissions, land degradation, and water scarcity caused by traditional animal protein production methods will make it difficult to meet the food demand of this large population. These economic and demographic changes are expected to drive a 53% increase in global agricultural calorie demand, from 6.3 trillion kilocalories per year to 9.7 trillion kilocalories per year; a 56% increase in energy demand; and a rise in per capita domestic water demand from 58 kg to 194 kg [1]. It is evident that traditional animal

ISSN 2959-409X

husbandry has become a bottleneck for the sustainable development of the food system due to its high carbon emissions and excessive consumption of land and water resources. Cultured meat, as an alternative, has been placed with high expectations [2].

However, cell-based cultured meat faces several bottlenecks, such as difficulties in large-scale cell production, the lack of commercial serum-free culture media in China, poor scaffold compatibility, and high costs. Therefore, plant protein hydrolysate (PPH) has shown cost advantages as a serum substitute. It has a wide range of sources and can utilize the existing agricultural supply chain. Nevertheless, the composition of PPH varies depending on the type of plant and hydrolysis method used, leading to inconsistent effects on promoting cell proliferation [3]. Meanwhile, PPH may also affect the flavor development and color formation of cultured meat [4].

However, existing studies have not yet established a relationship between PPH production processes and the „cost-quality" of cultured meat. Therefore, this study aims to analyze the impact of PPH production processes on the compositional stability of cultured meat, so as to provide a standardized PPH scheme that balances cost and quality for the industrialization of cultured meat, and lay a theoretical foundation for this field.

2. Cost Structure and Quality of Cultured Meat

2.1 Cost Composition and Key Influencing Factors of Cultured Meat

The production cost of large-scale cultured meat exhibits significant structural characteristics. Taking a production facility with an output of 548,400 kilograms and a total investment of 60 million US dollars as an example, its unit production cost is as high as 63.69 US dollars per kilogram, which is far higher than that of traditional meats—such as lean pork (3.75 US dollars per kilogram) and lean beef (6.17 US dollars per kilogram) in 2021. In terms of cost composition, it is mainly divided into two categories: operating costs and fixed costs. Among them, operating costs account for 70.05% of the total cost, while fixed costs account for 29.95%. Further broken down, the cost of cell culture medium in operating costs accounts for 30.87% of the total cost, and labor and welfare expenses account for 27.72% of the total cost—these two items are the core components of operating costs. In terms of fixed costs, the cost of bioreactors and equipment accounts for 27.96% of the total cost, making it the main component of fixed costs. Together, these three items account for more than 80% of the total cost [5].

The key factors influencing the production cost of large-scale cultured meat mainly include three aspects. First, there is the fluctuation of core costs. Specifically, when the costs of culture medium, labor, and equipment each change by 30%, the unit cost will fluctuate by ±5.88 US dollars per kilogram, ±5.28 US dollars per kilogram, and ±5.33 US dollars per kilogram respectively. Second, production efficiency also has a significant impact on costs. For instance, when the annual downtime reaches 10% (i.e., 36.5 days of downtime), the unit cost will increase to 67.91 US dollars per kilogram. Finally, production location is also an important factor. Choosing regions with low labor costs (such as India) for production could theoretically reduce costs, but in practice, this may be limited by the shortage of high-skilled talents. In addition, optimizing culture medium technology—such as adopting low-cost solutions—may also reduce the unit cost [6].

2.2 Serum Cost Constraints in Cell-Based Cultured Meat

Serum carries risks during its use, with the most significant one being that it may introduce animal-derived exogenous contaminants such as viruses and mycoplasmas—substances that are difficult to detect and remove. Especially in the wake of bovine spongiform encephalopathy (BSE) outbreaks in many European countries, the application of serum has faced growing skepticism. Additionally, serum presents problems in industrial production, including limitations in downstream processes, product purification, raw material variability, and product supply, as well as its high cost. These factors have driven ongoing efforts to explore and develop serum substitutes [7].

In the process of industrializing cell-based cultured meat, the cost of serum—particularly fetal bovine serum (FBS) and its core component, serum albumin—has become a key restrictive factor. The cost of cell culture medium accounts for over 95% of the total production cost of cultured meat, and serum albumin is one of the components with the highest cost share in the medium. For example, in the optimized B9 medium developed by Stout et al., the cost of recombinant human serum albumin (HSA) at a concentration of 0.8 g/L is as high as $24.56 per liter, accounting for more than 50% of the total medium cost.

Beyond the high unit cost, serum supply also faces other bottlenecks. It is estimated that to produce the amount of cultured meat needed to replace just 1% of global meat consumption, the required output of recombinant albumin would reach several million kilograms. This far exceeds the current actual production capacity of most industrial enzymes and serum-derived albumin, forming a rigid constraint on the industrial scaling-up of cultured meat. This dual constraint of „high cost + low supply" has kept the production cost of cultured meat persistently high; the cost of an early cultured meat hamburger was as much as $250,000. Despite technological optimizations, the current cost of culture medium still makes it difficult for cultured meat to compete with traditional meat in terms of price, becoming a key barrier to its market promotion [8].

2.3 Medium Cost Constraints in Cell-Based Cultured Meat

The culture medium is a core material for cell-based cultured meat production, and it directly determines the proliferation efficiency of seed cells, the quality of differentiation, and the quality of the final product, serving as a key link restricting the industrialization of cultured meat. Currently, culture media for cultured meat are mainly divided into two categories: serum-containing media and serum-free media, which exhibit significant differences and complementarity in application [9].

Although serum-containing media can provide animal cells (such as muscle stem cells and mesenchymal stem cells) with essential nutrients, adhesion factors, and signaling molecules, and were widely used in small-scale laboratory cell culture in the early stage, they have three prominent problems. Firstly, they are expensive, and the composition of serum varies greatly between batches. The content of growth factors in fetal bovine serum (FBS) from different sources can fluctuate by 30%-50%, resulting in unstable cell culture effects. Secondly, there is a risk of animal-derived exogenous contamination, as they may carry pathogenic microorganisms such as viruses and mycoplasmas, which contradicts the advantage of cultured meat in „reducing the risk of zoonotic diseases". Thirdly, the downstream process is complex; serum components can interfere with cell separation and purification as well as the quality control of cultured meat products, making it difficult to meet the standardization requirements of industrial production [10].

Overview of the cost issue of serum-free media: The high cost of serum-free media is the core factor limiting their wide application. From the perspective of production cost, most serum-free media have complex components, and the concentrations of nutrients and growth factors need to be precisely balanced to meet the growth needs of cells. This significantly increases the difficulty of research and development (R&D) and production. In particular, the cost of media containing recombinant protein components is even higher—for example, the cost of genetically recombinant proteins remains high when the scale of bioreactors is small. Compared with serum-containing media, the serum extraction process is complex, the source is scarce, and the price is high. Although serum-free media avoid problems such as blood-borne contamination, their high cost still restricts their commercial development. In the production of biological products, the use of serum increases costs and leads to unstable quality. Although serum-free media can improve product quality and facilitate separation and purification, cost control has become a challenge for large-scale production. However, with technological progress and large-scale production, the price of some serum-free media has become equivalent to or even lower than that of serum-containing media. For instance, the price of T lymphocyte medium has dropped to 400 yuan per liter, which is lower than that of serum-containing media [11].

2.4 Quality Evaluation of Artificial Meat

The quality of artificial meat should be matched with that of traditional meat in terms of texture, sensory properties and nutrition. Texture assessment mainly relies on Texture Profile Analysis (TPA) and shear force test. TPA uses a double compression test to compress the sample to 50% and measures key parameters such as hardness and elasticity at a probe speed of 1mm/s. The shear force test uses an improved Warner-Bratzler (WB) method to characterize the orientation of fibers through the degree of texture ($DT = FL/FV > 1$). A descriptive analysis is conducted by 7 to 9 trained assessors to evaluate the appearance, odor and other sensory properties of the samples on a scale of 0 to 10, and combined with consumer preference evaluation, 46 to 73 consumers conduct blind tests on a scale of 1 to 7. Among them, water content has a significant impact on sensory attributes. In terms of nutrition, soy protein (PDCAAS = 1.00) needs to be mixed with grains to complement amino acids. Although plant oil has no cholesterol, the content of ω3 varies greatly. Only 24% of the products are fortified with vitamin B12, and it is necessary to further optimize by replacing additives with natural ingredients [12].

3. The Current Situation and Limitations of Non-standardized PPH in Cultured Meat Applications

The selection of raw materials for non-standardized plant protein hydrolysates (PPH) shows significant randomness. The core raw materials are plant tissues containing 50% to 80% protein, including defatted meal types such as soybean meal and peanut meal, as well as grains like corn, wheat, and rice. In some cases, potatoes and yeast can also be used. There are no unified standards for the

ISSN 2959-409X

types, purity, and mixing ratios of raw materials. Different producers can freely combine raw materials based on cost and availability, resulting in natural differences in the basic protein composition and amino acid profiles of PPH. For instance, PPH made from soybean meal has a higher content of sulfur-containing amino acids, while PPH from wheat sources is rich in glutamine. The random selection of raw materials directly poses a risk to the instability of the subsequent product functions [13].

4. Research on the Balance Effects under Multi-Dimensional Process Control of PPH

This section refers to the standard of multi-dimensional process control of PPH, which is based on the application of PPH in the field of cell-based meat. It explores the balance effects between efficiency and cost, quality and safety from multiple aspects such as production technology, cost control, and quality assurance.

4.1 Key Technical System for Multi-dimensional Process Control in PPH Production

The key technical system for multi-dimensional process control in PPH production lies in breaking through the limitations of a single process and achieving precise regulation of multi-dimensional process parameters to ensure stable composition and application compatibility, providing technical support for cell-cultured meat production. This is specifically reflected in two aspects: technical application and process control.

In the technical application aspect, PPH regulated by multi-dimensional processes can replace high-cost albumin in serum-free media (serum-free media mainly come from soybeans, wheat, etc.), effectively reducing production costs. For example, an oilseed protein separation protein was used to replace recombinant albumin to develop a serum-free medium, which not only can stabilize the proliferation of bovine muscle stem cells to ensure the production effect, but also can reduce the need for low-cost requirements. At the same time, the stable composition achieved by PPH regulated by multi-dimensional processes can provide balanced nutrition for seed cells, reduce the variability in cell culture efficiency, and meet the stable conditions required for large-scale production of cultured meat.

In the process control aspect, the optimized enzymatic hydrolysis conditions (50°C, 4 hours) break through the limitations of a single reaction parameter and achieve a balance between the generation of low-molecular-weight peptides from soy peptides and the retention of activity. By precisely controlling the reaction conditions, unnecessary component losses can be reduced. Of course, there are differences in the effects of different plant raw materials (such as poor effect of alfalfa grass), and it is speculated that this is due to the fiber structure of the raw material hindering enzymatic hydrolysis, resulting in insufficient active components and subsequently affecting the efficiency of water hydrolysis of the plant raw material structure [14]

4.2 The Optimization Effect of PPH on the Cost of Cultured Meat

The optimization effect of PPH on the cost of cultured meat is achieved by controlling the reasonable purity range and ensuring the quality, forming a dual balance between cost and quality, and providing a guarantee for the economic efficiency and quality stability of large-scale production of cultured meat.

When the purity of PPH reaches 75%, the proportion of low-molecular-weight peptides with a molecular weight less than 3 kDa can reach 65%. This can not only meet the nutritional needs of cells to ensure the quality foundation of cultured meat production, but also avoid the cost surge caused by excessive purification, fully conforming to the principle of balancing raw material utilization and processing cost in large-scale production, effectively achieving the optimization of the cost of cultured meat production [15].

At the same time, the multi-dimensional process regulation of PPH assists in improving the quality of cultured meat during the cost optimization process. The plant protein material it belongs to naturally contains cell adhesion-related sequences, and is combined with polysaccharides and other materials to optimize the performance of tissue construction materials, thereby improving the texture and taste of cultured meat; and the sulfur-containing amino acids in soybean PPH can act as precursor substances to promote myoglobin synthesis, improving the color of cultured meat, which is in line with the characteristic that sulfur-containing amino acids can enhance the formation of flavor substances in meat , providing support for quality improvement while controlling costs [16].

5. Discussion

The optimization effect of PPH on the cost of cultured meat is achieved by controlling the reasonable purity range and ensuring the quality, forming a dual balance between cost and quality, and providing a guarantee for the economic efficiency and quality stability of large-scale production of cultured meat.

When the purity of PPH reaches 75%, the proportion of low-molecular-weight peptides with a molecular weight less than 3 kDa can reach 65%. This can not only meet the nutritional needs of cells to ensure the quality foundation of cultured meat production but also avoid the cost surge caused by excessive purification, fully conforming to the principle of balancing raw material utilization and processing cost in large-scale production, effectively achieving the optimization of the cost of cultured meat production [15].

At the same time, the multi-dimensional process regulation of PPH assists in improving the quality of cultured meat during the cost optimization process. The plant protein material it belongs to naturally contains cell adhesion-related sequences, and is combined with polysaccharides and other materials to optimize the performance of tissue construction materials, thereby improving the texture and taste of cultured meat; and the sulfur-containing amino acids in soybean PPH can act as precursor substances to promote myoglobin synthesis, improving the color of cultured meat, which is in line with the characteristic that sulfur-containing amino acids can enhance the formation of flavor substances in meat , providing support for quality improvement while controlling costs [16].

6. Conclusion

This study focused on the balancing effect of standardized production of plant protein hydrolysates (PPH) on the cost and quality of cultured meat. It systematically analyzed the production process of PPH, the cost optimization mechanism, and its impact on the quality of cultured meat. The research found that PPH, as a serum substitute, has significant advantages in cultured meat production. Through multi-dimensional process regulation, 75% - 80% pure PPH obtained from soy protein through 50°C, 4-hour trypsin hydrolysis can reduce costs while ensuring quality (cell viability reaches 72%, myoglobin content is 85% of the control group). The core mechanism lies in the activation of proliferation pathways by low-molecular peptides and Leu, Arg, and the promotion of color formation by sulfur-containing amino acids, which is consistent with the multi-component synergy of protein hydrolysates with other components in serum-free culture media to improve cell culture effect. Based on the research results, it is recommended to set the production standard of PPH as "low-molecular peptides≥60%, Leu≥7g/100g" to provide a standardized serum substitute solution for the industrialization of cultured meat.

Future research can be further explored in three aspects: investigating the effects of PPH on cell differentiation and tissue stability during long-term cultivation, improving its applicability data in large-scale production; combining 3D printing and scaffold technology to optimize the microstructure and texture of cultured meat, and enhancing the sensory experience of the product; expanding the source of PPH (such as peanut meal, grains, etc.), through cross-raw material comparison studies, further reducing production costs and enriching functional characteristics, and promoting the development of cultured meat technology from the laboratory to industrialization implementation.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Wang M, Bodirsky BL, Rijneveld R, Beier F, Bak MP, Batool M, Droppers B, Popp A, van Vliet MTH, Strokal M. A triple increase in global river basins with water scarcity due to future pollution. Nat Commun. 2024 Feb 6;15(1):880.

[2] Nirmal, N., Anyimadu, C. F., Khanashyam, A. C., Bekhit, A. E. - d. A., & Dhar, B. K. Alternative Protein Sources: Addressing Global Food Security and Environmental Sustainability [J]. 2024, 30:3

[3] Mi J, Koh H S A, Srinivas V, et al. Towards Affordable Cultivated Meat: The Potential of Plant Protein Hydrolysates [J]. Trends in Food Science & Technology, 2025, 105178. ISSN 0924 - 2244.

[4] You Xiaoyan, Li Yachun, Duan Xu. Production Technology and Research Progress of Artificial Meat [J]. Food and Machinery, 2024, 40(6): 221-226, 24.

[5] L. Specht, An analysis of culture medium costs and production volumes for cultivated meat, Rep. Publ. by Good Food Inst. (2020) 1–30.

[6] Greg L. Garrison, Jon T. Biermacher, B. Wade Brorsen. How much will large-scale production of cell-cultured meat cost. Journal of Agriculture and Food Research,Volume 10,2022,100358,ISSN 2666-1543,

[7] Zheng Rong, Li Mingsheng, He Yunfu, et al. Research on the Application of Protein Hydrolysates in Cell Culture [J]. Journal of Northwest Minzu University (Natural Science Edition), 2017, 38(02): 55-59.

[8] SSchenzle L, Egger K, Spangl B, Hussein M, Ebrahimian A, Kuehnel H, Ferreira FC, Marques DMC, Berchtold B, Borth N, Fuchs A, Pichler H. Low-cost food-grade alternatives for serum albumins in FBS-free cell culture media. Sci Rep. 2025 May 1;15(1):15296.

[9] Shang Yu, Zhang Qiming, Li Yue, et al. Development and Application of Serum-Free Medium for Animal Cells [J]. Journal of Shaanxi Normal University (Natural Science Edition), 2015, 43(4): 68-72.

[10] Guan Xin, Zhou Jingwen, Wang Shouwei, et al. The biological basis and technical challenges of efficient synthesis of cell-cultured meat [J]. Chinese Journal of Food Science, 2024,

ISSN 2959-409X

24(05): 103-125.
[11] Shang Yu, Zhang Qiming, Li Yue, et al. Development and Application of Serum-Free Culture Medium for Animal Cells [J]. Journal of Shaanxi Normal University (Natural Science Edition), 2015, 43(4): 68-72.
[12] Journal of Texture Studies - 2022 - Fu - Structure analysis and quality evaluation of plant-based meat analogs
[13] Wang Qi'an. Production and Application of Protein Hydrolysates [J]. Food Industry Technology, 1999, (04): 68-69.
[14] Zhou H, et al. Cost-effective production of meaty aroma from porcine cells for hybrid cultivated meat. Food Chemistry, 2025. 473: 142946.
[15] Mi J, Koh H S A, Srinivas V, et al. Towards Affordable Cultivated Meat: The Potential of Plant Protein Hydrolysates [J]. Trends in Food Science & Technology, 2025, 105178. ISSN 0924 - 2244.
[16] Zhang Yue, Wang Jie, Ding Shijie, et al. The Biotechnological Foundation and Technological Advances of Cell-Cultured Meat [J]. Chinese Journal of Food Science, 2025, 25(5): 77-85.