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ADVANCES IN PROTEIN SYNTHESIS TECHNOLOGY AND THEIR IMPLICATIONS FOR FUTURE PROTEIN AVAILABILITY: A NARRATIVE REVIEW

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Abstract: *The availability of conventional protein sources is increasingly limited due to population growth, climate change, and limited land, so innovation is needed in providing more efficient and sustainable protein. This study aims to examine the development of protein synthesis technology and its implications for the availability of future protein sources. The method used is a literature review by examining scientific publications published from 2015-2024 searched through Google Scholar. The results of the study indicate that recombinant technology is able to produce high-quality functional proteins through genetic engineering of microorganisms, while microbial fermentation based on agro-industrial waste offers cheap and environmentally friendly Single Cell Protein production. In addition, increased production of poultry, eggs, and milk is the main support for the national animal protein supply. Overall, the development of protein synthesis technology provides a strategic opportunity to meet global protein needs through a resource-efficient, scalable, and sustainability-oriented approach.*

Abstrak: Ketersediaan sumber protein konvensional semakin terbatas akibat pertumbuhan penduduk, perubahan iklim, dan keterbatasan lahan, sehingga diperlukan inovasi dalam penyediaan protein yang lebih efisien dan berkelanjutan. Penelitian ini bertujuan mengkaji perkembangan teknologi sintesis protein serta implikasinya terhadap ketersediaan sumber protein masa depan. Metode yang digunakan adalah literatur review dengan menelaah publikasi ilmiah terbitan 2015-2024 yang ditelusuri melalui Google Scholar. Hasil kajian menunjukkan bahwa teknologi rekombinan mampu menghasilkan protein fungsional berkualitas tinggi melalui rekayasa genetik mikroorganisme, sementara fermentasi mikroba berbasis limbah agroindustri menawarkan produksi Single Cell Protein yang murah dan ramah lingkungan. Selain itu, peningkatan produksi unggas, telur, dan susu menjadi penopang utama penyediaan protein hewani nasional. Secara keseluruhan, perkembangan teknologi sintesis protein memberikan peluang strategis bagi pemenuhan kebutuhan protein global melalui pendekatan yang hemat sumber daya, scalable, dan berorientasi keberlanjutan.

INTRODUCTION

Proteins are complex organic compounds with high molecular weights composed of amino acid chains linked together by peptide bonds. These molecules play an important role in various biological processes, including as enzymes, hormones, and antibodies. In order to perform these functions, newly synthesized polypeptides must undergo a folding process to form stable three-dimensional structures so that they can play a role in metabolic catalysis and other cellular activities (Hetrik et al., 2024). Along with global population growth and increasing nutritional needs, the demand for protein sources has also increased significantly.

Based on research by Rahakbauw & Samputra (2025), it is explained that the increasing population and urbanization have caused food demand to rise while agricultural land has shrunk due to land conversion. This condition is exacerbated by a market structure dominated by a handful of traders, a long supply chain, and the impact of climate change. This situation poses a serious challenge, given that the availability of conventional protein sources, both animal and plant-based, is increasingly limited and unable to keep pace with demand. In addition, protein production from intensive livestock farming causes various environmental problems, so this situation calls for innovation in the provision of protein sources that are more efficient, sustainable, and capable of being produced on a large scale.

In the context of modern biology, protein synthesis is understood as the process of forming polypeptide chains from amino acids through the mechanisms of transcription and translation in cells. According to Az Zahra et al. (2025), protein synthesis is the process of forming proteins based on DNA instructions through two stages: transcription and translation. DNA is transcribed into mRNA, then ribosomes translate it into a sequence of amino acids that form proteins. At the biotechnology level, the protein synthesis process can be engineered by utilizing microorganisms as a production system. Microorga-nisms are very small and simple life forms, such as bacteria and fungi, which play an important role in various biological processes and can be utilized in biotechnology, including protein production. The ability of microorganisms to grow rapidly and metabolize efficiently makes them prime candidates for the development of controlled and sustainable protein production technology (Hamzah et al., 2023).

Protein sources basically include animal and plant proteins, as well as various foods that contain essential amino acids needed by the body. Various foods such as lean meat, eggs, low-fat milk, nuts, and soy products are referred to as high-quality protein

sources that have been the mainstay of human daily protein requirements. However, the journal also mentions that limited access to nutritious food in many regions of Indonesia has led to an imbalance in protein intake, making communities vulnerable to nutritional problems such as Protein-Energy Malnutrition (Rofidah et al., 2024). This condition shows that conventional protein sources are not always easily accessible or sufficient to meet the needs of a growing population. Therefore, alternative proteins such as plant-based proteins, insects, microproteins, and microalgae are needed as more sustainable alternatives to animal proteins (Turnagöl et al., 2023).

Based on research by Faridah & Sari. (2019), developments in the field of biotechnology have presented various new opportunities through the use of protein synthesis technology, both through genetic engineering and microbial fermentation processes. Recombinant DNA technology plays an important role in improving health conditions by developing new vaccines and medicines. Treatment strategies can also be improved by developing diagnostic kits, monitoring devices, and new therapeutic approaches (Yulianti, 2024). In recombinant techniques, microorganisms such as Escherichia coli can be engineered to produce specific types of high-quality proteins. Meanwhile, microbial fermentation enables the formation of Single Cell Protein (SCP) from yeast or bacteria (Musa'adah et al., 2025). These various breakthroughs offer more efficient and sustainable production processes, while also providing alternative protein sources that do not require large areas of land and have a much lower environmental impact compared to conventional protein production. Therefore, this literature review was conducted to provide an in-depth study of the development of protein synthesis technology and its implications for the availability of protein sources in the future.

METHOD

This study uses a literature review method by examining three relevant scientific publications related to the development of protein synthesis technology and its implications for the availability of future protein sources. Literature sources were obtained from international and national scientific databases, including Google Scholar, with a publication range of 2015-2024 to ensure the relevance and currency of the information. The search process was conducted using a combination of keywords such as Recombinant Protein Production, Single Cell Protein (SCP), and Microbial Protein Technology. Literature selection was based on relevance to the topic, data completeness, and research methodology quality. All selected sources were then

analyzed descriptively and comparatively to identify developments in protein synthesis approaches, ranging from genetic engineering, microbial fermentation, to co-culture, as well as their implications for the availability of future protein sources

RESULTS AND DISCUSSION

Results

Table 1. Implications of Protein Synthesis Technology

No.	References	Research Focus	Key Findings	Synthesis	Implications for the Future
1	Hermana *et al*. (2015)	Recombinant protein synthesis in E. coli BL21	Optimization of incubation and lysis increases recombinant protein production.	Recombinant technology effectively produces high-value proteins.	Can be developed for more efficient production of vaccines, industrial enzymes, and biopharmaceutical platforms.
2	Harahap *et al*. (2024)	SCP production using S. cerevisiae on tofu waste	Medium MFLT2 provides the highest protein content; waste can be processed into SCP.	SCP is a cheap and sustainable protein alternative. .	It has the potential to become a mass source of protein for feed and food, supporting the circular economy and food security.
3	Priyono & Priyanti. (2018)	National availability of animal protein (meat, eggs, milk).	Poultry production is growing the fastest; cattle production is stagnant; egg and milk production is increasing. .	Indonesia relies on poultry and non-meat products as its main sources of protein.	Future policies need to strengthen the poultry sector, improve the efficiency of ruminant livestock, and encourage diversification of animal protein.

Source: Hermana, (2015)., Harahap, (2024)., Priyono & Priyanti, (2018)

Based on Table 1 above in Journal 1, it describes the development of protein synthesis technology through genetic engineering using Escherichia coli BL21 as the expression host. The antigenic gene of Mycobacterium tuberculosis was transformed into E. coli, so that this bacterium could act as a high-value recombinant protein production system. Culture optimization, particularly incubation time and cell lysis methods, has been shown to determine the success of protein synthesis, with 12-hour incubation and the freeze-thaw method producing the highest protein levels. This indicates that the recombinant protein synthesis process is greatly influenced by cell growth conditions and the cell lysis technique used. This innovation is an important basis for the use of recombinant technology as a future source of protein, as it is capable of producing functional proteins quickly, in a standardized manner, and in large quantities. Thus, in Journal 1, it can be concluded that recombinant protein technology

has great potential to increase the availability of high-value proteins, especially for medical and industrial needs, and indicates the direction of development of precision-based protein synthesis technology (Hermana et al., 2015).

In journal 2, the emphasis is on the use of microbial fermentation as an alternative protein synthesis technology through the production of Single Cell Protein (SCP). Tofu wastewater is used as a medium because its nutritional content supports the growth of Saccharomyces cerevisiae. The results of the study show that the MFLT2 medium enriched with nitrogen and phosphate produces the highest protein content compared to other media. The decrease in glucose levels during fermentation indicates that the substrate is actively metabolized for biomass and protein synthesis. The use of agro-industrial waste as a substrate is an environmentally friendly, economical, and industrial-scale protein production strategy (Harahap et al., 2024).

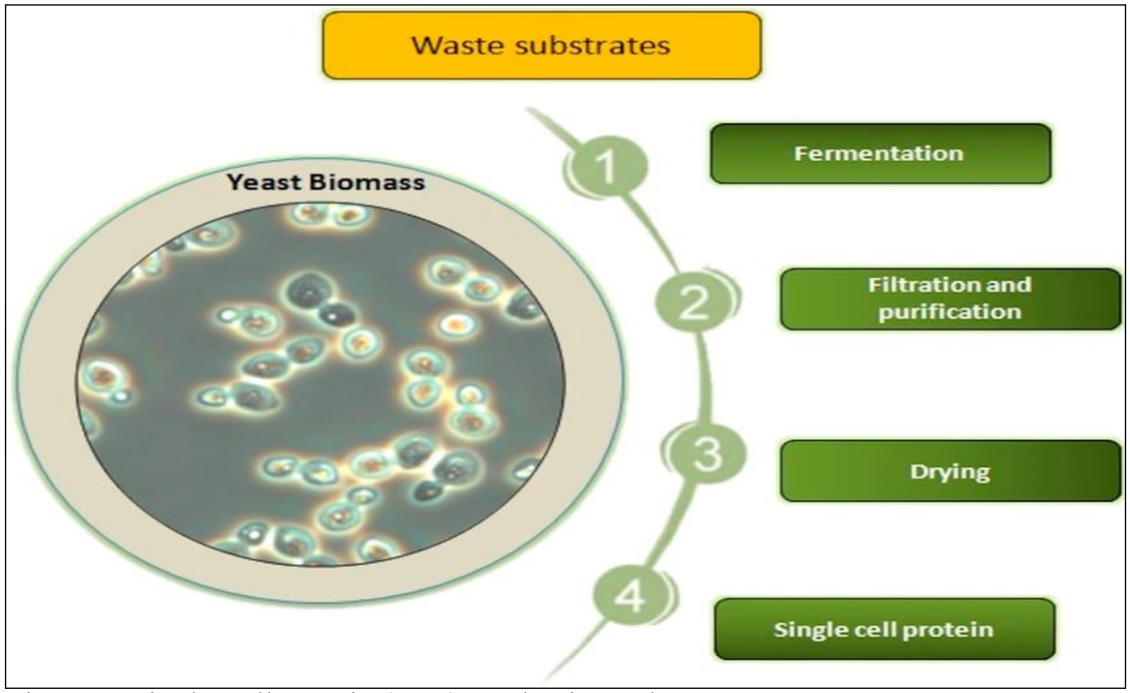

Figure 1. Single Cell Protein (SCP) Production Scheme

Based on Figure 1, SCP is agricultural, food, and industrial residue and waste, and is a potential substrate for microbial protein production. Obtaining microbial protein by converting waste substrates into value-added feed and food, as highly nutritious protein biomass, thereby reducing environmental pollution, is a very important and valuable feature of SCP production (Jach, 2022). Therefore, as seen in Journal 2, SCP technology is not only a sustainable solution for waste management but also provides an affordable, rapidly produced alternative protein source with the

potential to meet future human protein and animal feed requirements (Harahap et al., 2024).

In journal 3, we analyze the development of national animal protein availability based on meat, egg, and milk production between 1994 and 2015. The results show that almost all animal protein commodities experienced positive growth, with the highest increase coming from the poultry sector. Broiler chicken meat was the largest contributor with a growth rate of 6.67% per year, making it the main source of protein for the community because it is more affordable and its production is stable. In contrast, beef and buffalo meat production tended to stagnate, with their share of production even declining to less than 25%, indicating that the public is increasingly shifting to more economical sources of protein. In addition, egg and milk production also showed a consistent upward trend, with chicken eggs growing by nearly 6% per year and milk by around 4% per year. This increase indicates diversification in animal protein consumption, whereby the population no longer relies solely on meat but also utilizes non-meat livestock products. Overall, this journal emphasizes the importance of developing poultry, eggs, and milk as the main pillars of national protein fulfillment. Thus, journal 3 shows that the increase in animal protein availability in Indonesia is largely supported by the poultry sector and non-meat products such as eggs and milk. The dominance of poultry in national production indicates that affordable and easily accessible protein sources are the primary choice for the public. This study reinforces the urgency of diversifying livestock production and strengthening the poultry industry to meet the growing demand for protein (Priyono & Priyanti, 2018).

Overall, the three journals show the development of future protein supply technologies and strategies through different but complementary approaches. Journal 1 highlights recombinant protein synthesis technology based on genetic engineering, journal 2 emphasizes the production of Single Cell Protein (SCP) from agro-industrial waste using microbial fermentation, while journal 3 provides a macro perspective on the availability of national animal protein through increased production of poultry, eggs, and milk. All three show the same direction, that the future of protein fulfillment does not only depend on conventional sources, but also requires biotechnology innovation, the utilization of microorganisms, and the optimization of efficient and sustainable livestock production. With this multidimensional approach, future protein supply can be safer, more stable, environmentally friendly, and economical.

CONCLUSION

Based on the results of the literature review, it can be concluded that meeting future protein needs requires innovation that goes beyond conventional sources. Protein synthesis technology has shown significant developments through three main approaches: recombinant protein production based on genetic engineering, Single Cell Protein (SCP) production through microbial fermentation of agro-industrial waste, and optimization of national animal protein availability through increased poultry, egg, and milk productivity. These three approaches complement each other by offering more efficient, sustainable, and resource-efficient protein production. Thus, protein synthesis technology has great potential to become a strategic solution in strengthening food security and ensuring the availability of stable, affordable, and environmentally friendly protein sources in the future.

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