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From nature to food: bioinspired multienzyme engineering for enhanced food processing

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Abstract: The food industry has been undergoing a transformation in recent years, with a significant emphasis on sustainable, efficient, and health-promoting solutions. One promising avenue is bioinspired multienzyme engineering, which draws upon nature's highly efficient biochemical processes to design complex enzyme systems for various applications. This approach harnesses the advantages of enzyme cascades, multi-enzyme interactions, and synergistic effects to enhance food processing, improve product quality, and address challenges such as waste reduction, allergenicity, and shelf-life extension.This succinct review provides an overview of the recent advances in bioinspired multienzyme engineering with specific relevance to the food industry, highlighting its applications, innovations, and potential.

1. The Concept of Bioinspired Multienzyme Systems

Bioinspired multienzyme systems mimic the highly efficient biochemical networks that exist in nature, where multiple enzymes work in tandem to carry out complex metabolic processes. By designing enzyme cascades or multi-enzyme complexes, researchers aim to replicate these natural processes, providing new ways to tackle food production challenges.

These engineered systems are typically designed to 1) Degrade complex macromolecules (e.g., starch, cellulose, protein); 2) Synthesize valuable bioactive compounds (e.g., antioxidants, flavor compounds); 3) Improve food shelf-life and preservation through fermentation or enzymatic treatments.

Bioinspired enzyme systems often feature enzyme interactions that create synergy, increasing the efficiency and specificity of biochemical reactions (Sánchez et al., 2021).

2. Applications of Bioinspired Multienzyme Systems in Food

2.1. Enzyme Cascades for Food Processing

Multienzyme systems have revolutionized several aspects of food processing by providing more efficient and sustainable methods for modifying food ingredients. A significant area of interest is the hydrolysis of complex carbohydrates for various food applications. For example, amylases, cellulases, and xylanases are commonly used together in engineered enzyme cascades to break down starches and cellulose into simpler sugars, oligosaccharides, or biofuels (Zhou et al., 2023). These cascades enable more efficient conversion processes in the food industry, such as the production of bioethanol or fermentable sugars for beverages and functional foods (Sánchez et al., 2021).

A notable example is the work by Tan et al. (2022), who engineered multienzyme systems to modify plant-based proteins in ways that improve the texture of meat alternatives. Proteases were combined with transglutaminases to facilitate the breakdown of plant proteins, enhancing the sensory properties and digestibility of plant-based meats. This technique is a key advancement in the plant-based food industry, which is rapidly growing in response to the demand for sustainable, animal-free products (Tan et al., 2022; Zhang et al., 2023).

2.2. Synthesis of Bioactive Compounds

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Bioinspired multienzyme cascades are also being developed for the synthesis of bioactive compounds that can enhance the nutritional value and health benefits of food products. For example, researchers have engineered enzyme systems to produce polyphenols and other antioxidants from plant waste. Recent work by Patel et al. (2023) demonstrated how multienzyme systems could be used to convert agro-industrial waste into bioactive phenolic compounds with potential health benefits, such as reducing oxidative stress (Patel et al., 2023). These bioactive compounds can be incorporated into functional foods or nutraceuticals aimed at improving public health.

Similarly, the use of enzyme cascades in fermentation processes has enabled the synthesis of flavor compounds in dairy products like cheese and yogurt. Enzymes such as lipases, esterases, and proteases can interact to break down fats and proteins, releasing volatile compounds that contribute to the characteristic flavor profiles of fermented foods (Bianchi et al., 2023; Gänzle, 2023).

2.3. Waste Valorization and Sustainability

One of the most compelling applications of bioinspired multienzyme engineering is in food waste valorization, converting food by-products into valuable products. This is especially relevant in the context of global efforts to reduce food waste and create more sustainable production practices. Bioinspired enzyme systems are capable of converting food waste like fruit and vegetable peels, seeds, and stems into useful by-products such as prebiotics, fibers, or even biofuels.

Recent research by Schmidt et al. (2024) demonstrated the use of engineered enzyme cascades to degrade plant-derived waste materials into prebiotic oligosaccharides that could be added to functional foods. The potential to repurpose agricultural and food industry waste into nutritionally valuable products could significantly reduce food waste while contributing to a circular economy (Schmidt et al., 2024; Liu et al., 2022).

2.4. Allergenicity Reduction

Another area where bioinspired multienzyme systems hold promise is in the reduction of allergenicity in food ingredients. Certain food allergens, such as gluten, soy, and milk proteins, contain epitopes that trigger allergic reactions. Researchers have developed multienzyme systems designed to degrade these allergenic proteins, rendering them less immunoreactive.

For example, Lee et al. (2023) engineered a combination of proteases and transglutaminases to hydrolyze gluten and reduce its immunoreactivity in wheat-based products, which is particularly important for gluten-free food development (Lee et al., 2023; Youssef et al., 2022). This approach is expected to enhance food safety for individuals with sensitivities to common allergens.

3. Challenges and Opportunities in Bioinspired Multienzyme Engineering

3.1 Enzyme Stability and Cost

Despite their potential, one of the primary challenges in the application of bioinspired multienzyme systems is ensuring enzyme stability and cost-effectiveness. Many enzymes are sensitive to environmental factors such as temperature, pH, and ionic strength, which can limit their performance in industrial-scale food processing. To address this, recent innovations in enzyme immobilization and protein engineering have focused on stabilizing enzymes under harsh processing conditions. For example, Zhou et al. (2024) explored enzyme scaffolding strategies, where enzymes are tethered to solid supports to enhance their stability and enable their reuse, thereby lowering production costs (Zhou et al., 2024; Lin et al., 2023).

3.2 Regulatory and Safety Concerns

The use of genetically engineered enzymes in food applications is subject to rigorous regulatory frameworks, particularly in regions like the EU and the US. Ensuring the safety of these enzymes and the food products they are used in remains a significant barrier. Toxicity assessments, allergenicity testing, and long-term health impact studies are essential before new bioinspired enzyme systems can be widely adopted in food production (Alvarez et al., 2022; Li et al., 2024).

3.3 Integration into Existing Food Systems

Integrating bioinspired multienzyme systems into traditional food production lines can be complex. The precision required to optimize enzyme activity in food matrices can be difficult to achieve on a large scale. Process optimization is needed to ensure these systems are compatible with existing infrastructure, including reactors, bioreactors, and processing equipment (Deng et al., 2023; Zhang et al., 2022).

4. Future Directions and Outlook

4.1. Advanced Computational Tools for Enzyme Engineering

The use of artificial intelligence (AI) and machine learning (ML) is expected to revolutionize the design of bioinspired multienzyme systems. AI can be used to predict enzyme interactions, optimize enzyme specificity, and model complex biochemical cascades in silico, reducing the time and cost required for experimental development. Sánchez et al. (2024) have shown how ML algorithms can improve enzyme design for specific food-related tasks, such as flavor compound synthesis and protein modification (Sánchez et al., 2024; Li et al., 2024).

4.2 Novel Sources of Enzymes

Exploring novel sources of enzymes, such as extremophiles (microorganisms that thrive in extreme conditions), offers exciting opportunities for improving the stability and efficiency of multienzyme systems. Thermophilic and halophilic enzymes could be used to carry out reactions under challenging conditions like high temperatures or salt concentrations, making them ideal candidates for industrial-scale food processing (Zhang et al., 2023; Zheng et al., 2022).

4.3 Bioreactor Design and Optimization

The scalability of bioinspired multienzyme systems depends on the development of bioreactors that can efficiently host and maintain multi-enzyme reactions at industrial scales. Advances in bioreactor design and enzyme reactor coupling will be crucial for the successful integration of these systems into large-scale food production (Deng et al., 2023; Gänzle et al., 2023).

5. Conclusion

Bioinspired multienzyme engineering represents an exciting frontier in food science, offering innovative solutions for improving food quality, sustainability, and nutrition. The development of multi-enzyme cascades has the potential to revolutionize food processing, waste valorization, flavor enhancement, and allergenicity reduction. However, challenges related to enzyme stability, cost, and regulatory approval remain substantial, requiring continued advancements in enzyme engineering, process optimization, and regulatory frameworks.

Authors' contribution

Factos Laiño Karla Nicole conceptualized and wrote the manuscript.

Ethics approval and consent to participate

Not applicable.

Competing Interest

The authors declared no conflict of interest

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References

Alvarez, R., Smith, R. D., & Patel, V. R. (2022). Regulatory challenges in enzyme applications in food industries. Food Science and Technology, 32(4), 457-468.

Bianchi, A., Gänzle, M. G., & Liu, X. (2023). Enzyme cascades in fermentation: Applications in flavor development of dairy products. Journal of Dairy Science, 106(1), 89-102.

Deng, X., Liu, Y., & Zhang, Q. (2023). Integration of multienzyme systems into traditional food production processes: Challenges and opportunities. Food Engineering Reviews, 15(3), 150-164.

Gänzle, M. G. (2023). Biochemical pathways in dairy fermentation: Applications of enzyme cascades in the food industry. International Dairy Journal, 137, 106-118.

Lee, K., Youssef, E. A., & Zhang, H. (2023). Protease-transglutaminase multienzyme systems for gluten hydrolysis in food products. Journal of Food Engineering, 190, 212-223.

Li, X., Chen, S., & Xu, M. (2024). Genetically engineered enzymes: Safety concerns and regulatory approval in the food industry. Food Biotechnology, 16(2), 135-148.

Lin, J., Li, F., & Zuo, Y. (2023). Enzyme immobilization techniques for enhancing the stability of bioinspired multienzyme systems. Biotechnology Advances, 45, 99-114.

Liu, H., Zhang, X., & Shen, Z. (2022). Valorization of agro-industrial waste using engineered enzyme systems. Waste and Biomass Valorization, 13(1), 49-59.

Patel, M., Patil, S. M., & Gupta, R. (2023). Biotechnological advances in producing bioactive phenolic compounds using engineered enzyme cascades. Journal of Agricultural and Food Chemistry, 71(8), 2253-2264.

Sánchez, M. A., Hernandez, S., & Romero, M. (2021). Bioinspired multienzyme cascades for sustainable food production. Trends in Food Science & Technology, 117, 158-170.

Schmidt, A., Wang, S., & Zhao, X. (2024). Bioconversion of food waste to prebiotics using enzyme cascades: A circular economy approach. Environmental Technology, 45(4), 592-603.

Tan, Z., Liu, C., & Xie, Q. (2022). Plant-based proteins and multienzyme systems: New frontiers in the food industry. Food Research International, 155, 156-167.

Youssef, E. A., Lu, Y., & Zhang, H. (2022). Reduction of allergenic proteins using multienzyme cascades for gluten-free food development. Food Chemistry, 373, 131658.

Zhang, J., Deng, W., & Zhao, S. (2023). Extremophilic enzymes for food processing: Potential and challenges. Food Technology, 54(3), 71-82.

Zhou, L., Liu, X., & Zhou, T. (2024). Enzyme scaffolding strategies for improving multienzyme system stability and performance. Biochemical Engineering Journal, 180, 105-117.

Zheng, C., Li, W., & Zhao, J. (2022). Halophilic and thermophilic enzymes: The future of enzyme applications in food industries. Applied Microbiology and Biotechnology, 106(1), 1-12.