

Short Review on Microbial Transglutaminase (mTGase) as a Structuring Tool in Plant-Based Meat Alternatives: Mechanisms, Applications, Future Perspectives, Consumer Concerns and Market Adoption

Abstract

Plant-based meat alternatives continue to gain market relevance due to sustainability, ethical, and health considerations. However, replicating the texture, cohesion, and sensory attributes of animal-derived meat remains a major technological challenge. Microbial transglutaminase (mTGase), an enzyme that catalyzes covalent cross-linking between glutamine and lysine residues in proteins, has emerged as a promising structuring tool for improving protein network formation in plant-based systems. Produced via microbial fermentation, mTGase is calcium-independent and active across a broad range of food-processing conditions. This review summarizes the mechanism of action of mTGase, its reactivity toward major plant protein sources, and its functional role in comminuted, emulsified, and structured plant-based meat products. Particular emphasis is placed on the integration of mTGase with physical structuring technologies such as extrusion and shear-cell processing. Overall, mTGase represents a versatile enzymatic strategy for enhancing texture and cohesion while reducing reliance on synthetic binders in clean-label plant-based meat alternatives.

Keywords: microbial transglutaminase; plant-based meat; protein cross-linking; meat analogues; texture modification; regulatory classification; consumer perception; market adoption

1. Introduction

The global market for plant-based meat alternatives has expanded rapidly, driven by concerns related to sustainability, animal welfare, and human health. Despite significant advances in extrusion and shear-based processing technologies, achieving meat-like texture, elasticity, and structural integrity remains challenging. Plant proteins often exhibit weaker intermolecular interactions and lack the hierarchical organization characteristic of muscle proteins, resulting in products that may be crumbly, brittle, or insufficiently cohesive.

Enzymatic modification of plant proteins has gained attention as a complementary strategy to physical structuring. Among available enzymes, microbial transglutaminase (mTGase) has been widely studied for its ability to form stable protein networks and improve textural attributes in food systems [1]. While traditionally used in animal-based meat processing, mTGase is increasingly applied in plant-based meat analogues due to its microbial origin, functional versatility, and compatibility with clean-label formulation strategies [2].

2. Microbial Transglutaminase: Origin and Mechanism of Action

Microbial transglutaminase (EC 2.3.2.13) is most commonly produced by *Streptomyces mobaraensis* through fermentation. The enzyme catalyzes an acyl-transfer reaction between the γ -carboxamide group of glutamine residues and the ϵ -amino group of lysine residues, forming ϵ -(γ -glutamyl)-lysine isopeptide bonds [1,2].

These covalent cross-links are resistant to heat, mechanical shear, and pH changes, making mTGase particularly suitable for food systems subjected to thermal processing. In contrast to mammalian transglutaminase, mTGase is calcium-independent and exhibits activity over a wide pH range (approximately 5–8) and temperatures between 5 and 50 °C [1].

3. Reactivity of Plant Proteins toward Microbial Transglutaminase

3.1. Soy Protein and Wheat Gluten

Soy protein isolate and concentrate are among the most effective substrates for mTGase due to their favorable amino acid composition and molecular flexibility. Cross-linking of soy proteins results in enhanced gel strength, water-holding capacity, and firmness [1]. Wheat gluten exhibits particularly high reactivity toward mTGase because of its high glutamine content, making it well suited for elastic and fibrous meat analogue structures [2].

3.2. Legume Proteins

Proteins derived from peas, fava beans, and chickpeas generally show moderate reactivity toward mTGase. Their globular structure and, in some cases, limited lysine availability may restrict cross-linking efficiency. Several studies demonstrate that blending legume proteins with soy protein or wheat gluten significantly improves mTGase-mediated network formation and textural properties in plant-based meat analogues [3,4].

3.3. Cereal and Other Plant Proteins

Rice protein exhibits limited suitability as a primary substrate for mTGase due to low lysine content and poor solubility. Consequently, rice protein is typically incorporated as part of blended protein systems rather than used alone in mTGase-driven structuring applications [1].

4. Functional Role of Microbial Transglutaminase in Plant-Based Meat

4.1. Comminuted and Minced Products

In plant-based burger patties and minced meat analogues, mTGase functions primarily as a protein binder. Enzymatic cross-linking enhances particle adhesion, reduces crumbling during cooking, and improves firmness and water retention. Multiple studies report that mTGase

enables partial replacement of hydrocolloid binders such as methylcellulose while maintaining desirable textural properties [3,5].

4.2. Emulsified Products and Sausages

In emulsified plant-based products such as sausages and deli-style slices, mTGase promotes protein gelation and stabilizes fat–protein matrices. This results in improved sliceability, elasticity, and moisture retention, producing textures comparable to conventional meat emulsions [6].

4.3. Structured and Whole-Cut Meat Analogues

mTGase has also been applied in structured plant-based meats produced using extrusion, shear-cell, or layering technologies. In these systems, enzymatic cross-linking stabilizes aligned protein fibers and reduces fracture during post-processing. Synergistic effects between mechanical alignment and mTGase treatment have been reported, particularly in soy- and fava bean-based formulations [4,7].

5. Processing and Formulation Considerations

Commercial mTGase preparations are typically applied at levels of 0.1–1.0% (w/w), depending on protein concentration and desired texture [1]. Adequate hydration and mixing are critical to ensure substrate accessibility. The enzyme is generally inactivated during subsequent thermal processing above 70 °C, limiting residual activity in the final product [2].

mTGase may act synergistically with dietary fibers and low levels of hydrocolloids; however, excessive cross-linking can result in overly firm or rubber-like textures. In addition, polyphenols and reducing agents present in certain plant ingredients may inhibit enzymatic activity, necessitating careful formulation optimization [1].

6. Regulatory Status, Consumer Considerations and Market Adoption

Microbial transglutaminase is approved for food use in many regions. In the European Union, it is generally classified as a processing aid under Regulation (EC) No 1333/2008, while in the United States it holds Generally Recognized as Safe (GRAS) status [1]. As mTGase is typically inactivated during thermal processing, declaration on ingredient labels is not mandatory in the EU, which supports its use in clean-label formulations.

Available market and consumer research indicates that the use of mTGase has not significantly impeded the commercial adoption of plant-based meat alternatives [8–10]. For the majority of consumers, purchasing decisions are driven primarily by taste, texture, price, and perceived health benefits rather than by the presence of processing aids. Consequently, mTGase is widely used in mainstream plant-based products without measurable negative impact on acceptance.

However, within specific consumer segments—particularly vegan and clean-label-oriented consumers—regulatory classification and production transparency are of greater relevance. Although mTGase itself is of microbial origin and therefore technically vegan, concerns have been raised regarding the possible use of animal-derived components in fermentation media. While such concerns are largely reputational rather than safety-related, they influence formulation and sourcing strategies for premium vegan brands seeking to minimize perceived ethical risk [7–10].

Overall, regulatory status and consumer perception do not represent a fundamental barrier to mTGase adoption but rather a segmentation factor. Transparent communication, verified vegan fermentation processes, and alignment with brand positioning are increasingly used to manage consumer expectations in markets with high vegan consumer density, such as Germany and Nordic countries.

7. Future Perspectives

Future research is expected to focus on optimizing mTGase functionality in legume-rich formulations, integrating enzymatic cross-linking with fermentation and extrusion technologies, and reducing reliance on synthetic binders. Advances in enzyme formulation, protein pretreatment, and process control may further enhance the specificity and effectiveness of mTGase in plant-based meat analogues.

8. Conclusions

Microbial transglutaminase represents a versatile enzymatic strategy for improving texture, cohesion, and structural stability in plant-based meat analogues. By catalyzing covalent cross-linking between plant proteins, mTGase effectively complements physical structuring technologies and supports the development of products with enhanced meat-like characteristics. Its microbial origin, broad processing compatibility, and regulatory acceptance make it a valuable tool in next-generation plant-based meat formulations.

While regulatory classification as a processing aid raises transparency considerations for specific consumer groups, available evidence suggests that these concerns primarily affect premium vegan market segments rather than overall market adoption. Addressing such concerns through verified sourcing and transparent communication may further strengthen consumer trust without limiting technological applicability.

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