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THE ROLE OF LACTOFERRIN AND BETA-LACTOGLOBULIN IN IMMUNOBIOCHEMICAL PROCESSES OF WHEY POWDER

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Abstract
Among the biologically active proteins present in whey powder, lactoferrin and beta-lactoglobulin stand out as key components capable of modulating immunobiochemical processes. Lactoferrin is an iron-binding glycoprotein with high affinity for Fe^{3+} ions and is involved in antimicrobial defense, regulation of inflammatory responses, and antioxidant protection mechanisms. Beta-lactoglobulin, the major whey protein, is characterized by a lipocalin-type structure that enables binding and transport of hydrophobic ligands; moreover, during digestion it can be hydrolyzed into bioactive peptides that indirectly influence immune and redox processes. This article systematically reviews, based on scientific literature, the structural and functional characteristics of lactoferrin and beta-lactoglobulin, their immunobiochemical activity mechanisms, and their significance in food technology as well as prophylactic and therapeutic applications.

Keywords: Lactoferrin, beta-lactoglobulin, whey powder, immune system, bioactive proteins, immunobiochemistry, bioactive peptides.

Introduction

Whey powder is a raw material rich in high-value protein fractions and is widely used in functional foods, sports nutrition, clinical dietetics, and biotechnological developments. Among whey proteins, lactoferrin and beta-lactoglobulin are considered the most relevant molecules in terms of immunomodulatory potential. The multifaceted role of lactoferrin in the host defense system is associated with its involvement in iron metabolism, binding of pathogen components, and modulation of inflammatory mediators [2, 3]. The biological significance of beta-lactoglobulin, on the other hand, is explained by its ligand-binding transport properties and by the generation of peptides during proteolysis that can modulate physiological responses. From this perspective, joint consideration of these two proteins within the framework of immunobiochemical mechanisms provides a scientific basis for understanding the functional potential of whey powder [4, 5, 6].

Main Part

Lactoferrin is a globular glycoprotein belonging to the transferrin family; its molecule consists of two lobes, each capable of binding one Fe^{3+} ion. By sequestering iron and thereby implementing a

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"nutritional immunity" mechanism, lactoferrin inhibits bacterial growth. In addition, direct interactions with microbial membrane structures have been reported, resulting in bactericidal effects against certain microorganisms.

The immunobiochemical value of lactoferrin is not limited to its antimicrobial activity. It can modulate signaling pathways involved in inflammatory responses, interact with pathogen-associated molecular patterns (PAMPs), and thereby balance pro-inflammatory cascades [2]. Furthermore, by limiting iron-dependent free radical reactions, lactoferrin contributes to the reduction of oxidative stress and protects cellular membranes and biomacromolecules from damage [1, 3].

Beta-lactoglobulin constitutes the major fraction of whey proteins in ruminant milk and is characterized by a three-dimensional structure typical of the lipocalin family, namely a β-barrel architecture. This structure allows binding of vitamins, fatty acids, and other hydrophobic molecules, suggesting a potential biological transport function [4]. The immunobiochemical role of beta-lactoglobulin is often associated with its proteolytic degradation during digestion. Enzymatic hydrolysis can generate peptides with antioxidant, antimicrobial, or immunomodulatory activities, as reported in numerous studies. At the same time, beta-lactoglobulin may act as an allergen in certain populations; therefore, food technology approaches such as fermentation, hydrolysis, and thermal treatment aimed at reducing allergenicity are of particular importance. These approaches help to balance immune tolerance and product safety [5, 6, 7].

Methodology

This article was prepared using an analytical and theoretical approach, with the aim of systematizing the role of lactoferrin and beta-lactoglobulin in immunobiochemical processes of whey powder from both structural and functional perspectives. In the analysis of lactoferrin, its effects on immune and inflammatory responses, antimicrobial defense mechanisms, iron homeostasis, and redox balance were conceptually integrated [1, 2, 3, 11]. Regarding beta-lactoglobulin, particular attention was paid to its lipocalin-type structure, ligand-binding properties, the physiological role of bioactive peptides formed after proteolysis, and allergenicity factors [4, 7]. The sources used were mainly high-impact scientific reviews and widely cited original articles.

Analysis

The immunobiochemical effects of lactoferrin are multistage. First, by limiting iron availability to pathogens, lactoferrin enhances the mechanism of nutritional immunity, thereby inhibiting microbial proliferation and strengthening natural defense at mucosal and epithelial surfaces [1]. Second, lactoferrin can interact with molecules and receptors involved in inflammatory signaling, potentially binding certain pro-inflammatory stimuli or attenuating their downstream effects, thus preventing excessive immune activation [2]. Third, since iron-mediated Fenton reactions increase oxidative stress, lactoferrin's ability to bind free iron contributes to antioxidant protection and reduces tissue damage caused by oxidative chain reactions [3].

Analysis of beta-lactoglobulin indicates that its immunobiochemical significance should be interpreted by distinguishing between the intact protein and digestion-derived peptides. As an intact molecule, beta-lactoglobulin can bind and transport biologically active ligands due to its lipocalin structure, potentially supporting nutrient bioavailability [4]. During digestion, enzymatic hydrolysis releases peptides that may exhibit antioxidant, antimicrobial, and immunomodulatory effects, as documented in multiple studies [5, 6, 7]. However, the allergenic properties of beta-lactoglobulin may limit its practical use; therefore, reducing or modifying allergenic determinants through technological processing is a key aspect in the design of functional products [6, 7].

Results

According to the literature analysis, lactoferrin is regarded as a multifunctional molecule that enhances innate immune defense against pathogens, modulates inflammatory responses, and reduces oxidative stress. Beta-lactoglobulin plays an important role in nutrient transport mechanisms through ligand binding and can indirectly modulate immunobiochemical responses via bioactive peptides generated during digestion. Thus, sufficient scientific evidence supports the consideration of these proteins as targeted components in the design of functional foods and bioactive supplements based on whey powder.

Conclusion

Lactoferrin and beta-lactoglobulin are among the most important bioactive proteins of whey powder, and their roles in immunobiochemical processes are explained by multiple mechanisms. Lactoferrin is recognized as a polyvalent molecule that integrates antimicrobial defense, inflammation modulation, and antioxidant protection. Beta-lactoglobulin exerts functional effects through its lipocalin-type structure and digestion-derived bioactive peptides; however, its allergenicity necessitates careful technological control. Future experimental studies evaluating dose, food matrix, thermal and enzymatic processing, and bioavailability parameters in an integrated manner will further clarify the applied value of lactoferrin and beta-lactoglobulin.

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