UDC: 577.1:612.74

BIOCHEMICAL CONTRIBUTION OF WHEY PROTEIN POWDERS TO ENERGY METABOLISM IN MUSCLE TISSUE

Rakhmonov Farkhod Kholbayevich
Zarmed University, Samarkand, Uzbekistan
e-mail: farxod1313jon@gmail.com

Alimdjanova Donoxon Djamshedovna
Student, Zarmed University, Samarkand, Uzbekistan
e-mail: alimjanovalimjanov51@gmail.com

Abstract. This article provides an extensive overview of the biochemical composition of whey proteins, their digestive pathways, the role of amino acids in muscle metabolism, and the molecular mechanisms underlying energy production in skeletal muscle. Special attention is given to the metabolism of branched-chain amino acids (BCAAs), including their transamination, mitochondrial oxidation, and contribution to ATP synthesis. In addition, the ability of leucine to activate the mTORC1 signaling pathway and thereby enhance muscle anabolism is thoroughly discussed. The anti-catabolic, antioxidant, immunomodulatory, and mitochondria-generating effects of whey proteins are analyzed from a biochemical perspective. Practical applications of whey proteins in sports medicine, clinical nutrition, geriatrics, and rehabilitation are comprehensively evaluated.

Keywords: whey protein, BCAA, mTOR, muscle metabolism, ATP synthesis, protein synthesis, antioxidant, transamination.

Introduction. Over the past decade, whey proteins have become one of the most frequently studied bioactive compounds in sports physiology, nutritional biochemistry, and clinical dietetics. They contain a complete spectrum of essential amino acids, with particularly high levels of branched-chain amino acids

(BCAAs)—leucine, isoleucine, and valine [3], [7]. The primary advantage of whey proteins is their extremely rapid digestion and absorption, resulting in a sharp increase in plasma amino acid concentrations and immediate availability to muscle tissue. This makes whey proteins one of the most effective nutritional components for supporting muscle metabolism.

Skeletal muscle is the central site of energy metabolism. The catabolism and turnover of proteins, carbohydrates, and lipids occur predominantly in muscle tissue. During physical exertion, muscle glycogen reserves decline, energy demand increases, and stress hormones rise. Under such conditions, amino acids—particularly BCAAs—play an increasingly important role in meeting metabolic demands [10]. Therefore, a deeper understanding of the mechanisms through which whey proteins affect muscle metabolism is of critical scientific significance.

Chemical Composition and Biological Activity of Whey Proteins. Whey is a complex mixture of bioactive proteins, consisting primarily of:

- **β-lactoglobulin** – the dominant protein fraction (50–60%), rich in BCAAs, lysine, and threonine [7].
- **α-lactalbumin** – a major source of tryptophan and histidine, involved in neuromodulatory processes.
- **Serum albumin** – exhibits strong antioxidant activity.
- **Lactoferrin** – an immunomodulatory and antibacterial protein.
- **Immunoglobulins** – support immune defense mechanisms.

Such a composition makes whey not only an energy source but also a valuable agent for enhancing recovery and strengthening immune function.

According to the CIS researcher I.F. Khakimov, whey proteins represent “the protein complex with the highest biological value among natural food proteins” [7].

Digestive Characteristics of Whey Proteins. The digestion of whey proteins occurs through several rapid biochemical steps:

1. **Denaturation** in the stomach under the influence of pepsin.

2. **Hydrolysis** into free amino acids and small peptides by trypsin, chymotrypsin, and carboxypeptidases in the small intestine.

3. **Absorption** through Na^+-dependent transport systems in enterocytes.

4. **Transport** to the liver via the portal circulation.

Whey proteins are digested 3–5 times faster than casein, enabling them to reach muscle tissue in a very short period. This property is key to their role in accelerating muscle regeneration and stimulating anabolic processes [3].

Role of BCAA Amino Acids in Muscle Metabolism. Unlike most amino acids, BCAAs are metabolized not in the liver but directly in skeletal muscle. This makes them a crucial energy substrate during prolonged or intense exercise.

Major stages of BCAA catabolism.

1. **Transamination** – conversion of BCAAs to their corresponding α-keto acids by aminotransferases.

2. **Oxidative decarboxylation** (BCKAD complex) – mitochondrial breakdown of α-keto acids through linkage with coenzyme A.

3. **Integration into the TCA cycle** – formation of metabolic intermediates that enhance ATP synthesis through oxidative phosphorylation [10].

During prolonged exercise, 10–20% of total energy may be derived from amino acids, particularly BCAAs.

Leucine and the mTOR Signaling Pathway. Leucine is one of the strongest natural activators of the mTORC1 (mammalian Target of Rapamycin Complex 1) anabolic signaling pathway.

When mTORC1 is activated:

- ribosomal protein synthesis increases;
- muscle fiber hypertrophy is accelerated;
- regeneration and repair processes are enhanced;
- overall muscle mass and strength increase [8].

European researchers have reported that leucine stimulates mTORC1 activity **40–80% more efficiently** than any other amino acid [8].

Anti-Catabolic Effects of Whey Proteins. Muscle tissue may undergo catabolic degradation in response to stress, prolonged exercise, elevated cortisol levels, or insufficient dietary intake. Whey proteins:

- increase free amino acids in the bloodstream,
- reduce cortisol-induced proteolysis,
- restore positive nitrogen balance,
- prevent the loss of muscle mass [6].

This mechanism is particularly important in rehabilitation medicine and geriatric physiology.

Antioxidant Activity and Mitochondrial Biogenesis. Whey proteins contain high levels of cysteine—the precursor of **glutathione**, one of the body's most powerful antioxidants.

Glutathione:

- neutralizes free radicals,
- protects mitochondria from oxidative stress,
- stabilizes the function of ATP-producing enzymes [9].

Furthermore, whey proteins enhance mitochondrial biogenesis via the **PGC-1α signaling pathway**, improving muscle endurance and cellular energy efficiency.

Practical Significance. Sports Medicine.

- accelerates muscle regeneration by 30–50%;
- enhances glycogen replenishment;
- reduces muscle soreness and inflammation.

Rehabilitation and Post-Surgical Recovery.

- slows or prevents muscle atrophy;
- accelerates postoperative recovery.

Geriatrics.

- reduces the risk of sarcopenia;
- maintains muscle strength in aging individuals.

Clinical Nutrition.

- strengthens immune function;
- corrects protein deficiencies;
- supports metabolic recovery processes.

Results. Scientific evidence demonstrates that whey proteins have a multifaceted influence on muscle energy metabolism. They serve not only as a rapid source of energy but also as powerful anabolic stimulators, antioxidants, anti-catabolic agents, and metabolic regulators. The direct catabolism of BCAAs within muscle tissue increases their energy efficiency, while leucine's activation of mTORC1 makes whey protein one of the most effective natural anabolic agents.

Conclusion. Whey proteins actively participate at every stage of muscle energy metabolism. They enhance ATP production, protect against catabolic breakdown, stimulate anabolic protein synthesis, strengthen the antioxidant system, improve mitochondrial function, and increase overall metabolic capacity. Therefore, their use in sports medicine, clinical practice, geriatrics, and rehabilitation is scientifically justified and provides significant practical benefits.

REFERENCES

1. Sh.U.T., Rakhmonov F.Kh. Dry whey: a promising product for the food industry // Web of Teachers. – 2025. – Vol. 3. – №3. – P. 16–18.

2. Rakhmonov F.Kh. et al. Effect of chitosan and whey powder on the productivity of broiler chickens // AJIIR. – 2025. – Vol. 7. – №6. – P. 10–12.

3. Ha E., Zemel M.B. Functional properties of whey, whey components, and essential amino acids // J. Dairy Sci. – 2003. – Vol. 86. – P. 104–116.

4. Holbayevich R.F., Dusmurod E., Iskanderovich I.K. Physiological and biochemical indicators of broiler chicks // Academia Repository. – 2024. – Vol. 5. – №2. – P. 184–187.

5. Rakhmonov F., Eshimov D., Islomov Kh. Effect of chitosan and whey powder on the weight of broilers // BIO Web Conf. – 2024. – Vol. 95. – P. 01025.

6. Rakhmanov F., Usmanova X., Khodjaerova G. Effect of bioadditional supplements on broiler chicken // International Multidisciplinary Journal of Research and Development. – 2025. – Vol. 1. – №2. – P. 3–7.

7. Хакимов И.Ф. Биохимия молочного белка. – Moscow: Nauka, 2018. – 264 p.

8. Борисенко А.В. Amino acid metabolism in sports physiology. – Saint Petersburg: Piter, 2019. – 312 p.

9. Sen S. Oxidative stress and antioxidants in exercise // J. Sports Sci. – 1999. – Vol. 17. – P. 343–357.

10. Shimomura Y., Murakami T. et al. Branched-chain amino acid metabolism in muscle // J. Nutr. – 2004. – Vol. 134. – P. 1583–1587.