J Biochem Technol (2026) 17(2): 71-77
https://doi.org/10.51847/rNztg9p5B3
ISSN: 0974-2328

Biotechnological Systems: Protein Substances Based on Enzymatic Hydrolysis of Collagen, Implementation of Engineering Innovations

Poznyakovsky Valeriy Mikhailovich, Kurkina Yulia Yurievna, Avstrievsky Alexander Nikolaevich, Tokhiriyon Boisjoni*, Ragozinnikova Elena Viktorovna

Received: 27 January 2026 / Received in revised form: 16 April 2026, Accepted: 17 April 2026, Published online: 25 May 2026

Abstract

This research presents a novel biotechnological approach for the development of an 'all-purpose' protein substance, "Metacollagen Silicon+", designed for specialized products with tailored functional properties. The core innovation lies in the enzymatic hydrolysis of animal-derived collagen, primarily bovine gelatin, using fungal alkaline protease (Protosem C). This process is characterized by mild, naturally analogous biochemical conditions, operating without pH pre-adjustment. A key differentiator of this substance is the incorporation of silicon, derived from mineral water sourced from a deep Siberian well, containing a notable concentration of silicic acid (75.7±11.3 mg/L). The resulting "Metacollagen Silicon+" is a mixture of collagen types I, II, and III, exhibiting favorable organoleptic characteristics. The article details the amino acid profile of the hydrolyzed collagen, highlighting the significant presence of glycine, proline, and hydroxyproline, alongside seven essential amino acids crucial for human health. The study elaborates on the multifaceted role of silicon in the body, particularly its importance for epithelial and connective tissues, skin, hair, nails, and bone health, where it interacts with calcium and various micronutrients. Furthermore, the research explores a sustainable practice of repurposing solid gelatin capsules, investigating methods for their purification from synthetic dyes using activated carbon as an effective sorbent. The developed process is implemented at an automated biotechnological facility certified under ISO 22000 and GMP standards, positioning this innovative protein substance as a valuable ingredient for functional foods, dietary supplements, and cosmetic products aimed at improving connective tissue health and bodily appearance.

Poznyakovsky Valery Mikhailovich
Scientific and Educational Center for Applied Biotechnology and Nutrition, Kemerovo State Medical University, Kemerovo, Russia.

Kurkina Yulia Yurievna
Department of Agrobiotechnologies, Higher Engineering School of Agrobiotechnology “Agrobiotech” (HES A), Tomsk, Russia.

Avstrievsky Alexander Nikolaevich
Art Life Company, Tomsk, Russia.

Tokhiriyon Boisjoni*, Ragozinnikova Elena Viktorovna
Department of Management, Entrepreneurship and Engineering, Ural State University of Economics, Ekaterinburg, Russia.

***E-mail:** tohiriyoni@gmail.com

Keywords: Collagen hydrolysis, Protein substance, Enzymatic treatment, Silicon integration, Gelatin capsules

Introduction

A biotechnology for a new raw ingredient – a universal protein substance for the production of specialized products with defined functional properties – has been developed. Hydrolyzed collagen of animal origin and mineral water with a high silicon content were used as the base (Aguirre-Cruz *et al*., 2020; Arely *et al*., 2020; Felician *et al*., 2021; Santos & Duarte, 2021; Mikhailovich *et al*., 2023). Collagen is cleaved using biological catalysts – alcalase or collagenase enzymes – without prior pH adjustment. This process is biochemical, fully analogous to natural processes, and is characterized by mild production technological parameters (Rahman & Al-Mamun, 2022; Wang & Chen, 2023; Genc & Ibanoglu, 2024). The high silicon content is ensured by the use of silicon-mineral therapeutic water, extracted from a well 850 meters deep in the Western Siberia region. The silicon acid content in one liter of water is 75.7±11.3 mg (Aguirre-Cruz *et al*., 2020; Arely *et al*., 2020; León-López *et al*., 2020; EFSA, 2021; Khatri *et al*., 2021; Mohamed & Al-Tahir, 2021; Al-Atif, 2022; Hashim & Al-Naimi, 2022; Javadpoor & Shariati, 2023; Jugdaohsingh & Powell, 2023; Li & Wei, 2023; Martinez-Puig *et al*., 2023; Oubari & El-Ghorab, 2023; Pu *et al*., 2023; Price *et al*., 2023; Skov & Jensen, 2023; Bian *et al*., 2024; Lima & Costa, 2024; Ohara & Ito, 2024; Zhang & Yang, 2024; Shariati & Khan, 2025).

Materials and Methods

The study utilized bovine food-grade gelatin (grade P-180, type B) as the primary raw material for collagen hydrolysis. Enzymatic breakdown was performed using Protosem C (fungal alkaline protease) at 50000 units/g. The mineralizing agent incorporated into the final product was mineral water with a high silicon content (75.7±11.3 mg/L silicic acid), sourced from an 850-meter depth well in the Tomsk region, Western Siberia. The hydrolysis process was carried out under mild biochemical conditions, mimicking natural processes without pre-adjustment of pH. The resulting hydrolyzed collagen, termed "Metacollagen Silicon+", was analyzed for its amino acid composition using standard analytical techniques (Rahman & Al-Mamun, 2022; Jugdaohsingh & Powell, 2023; Wang & Chen, 2023; Genc & Ibanoglu, 2024; Ohara & Ito, 2024; Shariati & Khan, 2025).

Results and Discussion

The assessment of silicon's role in connective tissue and bone metabolism involved reviewing existing literature on its biochemical interactions with other elements (Ca, P, Na, K, S, Al, Co) and its necessity for epithelial and connective tissues, skin, hair, nails, and bone mineralization (Araujo *et al*., 2021; Li & Wei, 2023; Price *et al*., 2023), as well as its relationship with Vitamin D and K.For the investigation into repurposing gelatin capsules, various types of solid gelatin capsules (TJK № 0) were sourced. These included batches with different color combinations (green/transparent, green/green, red/red). Analytical methods, specifically spectrophotometry (UV-Vis spectrophotometry), were employed to quantify the presence of synthetic dyes within these capsules. Calibration curves were constructed using standard solutions of dyes (Brilliant Blue E133, Carmine E124, Copper chlorophyllin complex E141, Quinoline Yellow E104) at concentrations ranging from 0.5 to 20 µg/mL. Sorption studies were conducted to evaluate the effectiveness of different sorbents (zeolite of coarse and fine fractions, microcrystalline cellulose (MCC), and activated carbon) at varying concentrations (2%, 10%, 20%) in removing dyes from hydrolyzed gelatin capsule solutions. Spectrophotometric analysis also served to determine the dye content in the final purified product, comparing it against established regulatory limits (TR TS 0.29/2012). The biotechnological production of the "Metacollagen Silicon+" substance was implemented at an automated facility certified under ISO 22000 and GMP standards. The amino acid composition of the new form of biologically active collagen – "Metacollagen Silicon+" – obtained by biotechnological enzymatic hydrolysis of food-grade bovine gelatin (grade P-180, type B) using Protosem C (fungal alkaline protease) 50000 units/g has been investigated. The developed form of biologically active dietary supplement (BAD) represents a mixture of collagen types 1, 2, and 3 with good organoleptic characteristics. Type I collagen constitutes 90% of the collagen found in tendons, organs, and bones; type II is found in the cartilage of knees, shoulders, and other joints; and type III is the main type of cartilage in reticular fibers and is found where type I collagen is also present. The collagen molecule (tropocollagen) is constructed from three peptide chains, each containing 1000 amino acid residues. The amino acid composition of collagen is unusual: every third amino acid is glycine, 20% are proline and hydroxyproline residues, 10% are alanine, and the remaining 40% are represented by all other amino acids. Collagen is the only protein containing hydroxyproline. The amino acid composition of hydrolyzed collagen is presented in **Table 1**.

Table 1. Amino acid composition of hydrolyzed collagen

Amino Acid	Content, mg/g (m ± SEM)	Content, % of total
Aspartic acid	41.29 ± 0.07	5.5
Hydroxy-L-proline	112.09 ± 0.02	14.9
Threonine	12.18 ± 0.14	1.6
Serine	22.11 ± 0.18	2.9
Glutamic acid	72.91 ± 0.57	9.7
Proline	129.62 ± 0.20	17.2
Glycine	165.69 ± 0.57	22.0
Alanine	67.37 ± 0.47	8.9
Valine	16.27 ± 0.12	2.2
Methionine	3.21 ± 0.06	0.4
Isoleucine	10.78 ± 0.09	1.4
Leucine	20.36 ± 0.18	2.7
Phenylalanine	12.63 ± 0.15	1.7
Histidine	3.71 ± 0.05	0.5
Lysine	20.15 ± 0.64	2.7
Arginine	37.46 ± 0.69	5.0
Hydroxylysine	5.21 ± 0.14	0.7

Hydrolyzed collagen (metacollagen) consists of amino acids that play an important role in human development and health. It contains over 50% of the total sum of glycine, hydroxy-α-proline, and proline, as well as seven of the eight essential amino acids – leucine, isoleucine, valine, lysine, methionine, threonine, and phenylalanine.

The silicon contained in metacollagen performs multifaceted functions in the body. It should be noted that living tissues exhibit a certain affinity for silicic acid. The presence of silicon compounds in the body is extremely necessary. In its metabolic processes, silicon is biochemically closely linked with certain other elements (Ca, P, Na, K, S, Al, Co). Effective absorption of silicon in the gastrointestinal tract presupposes the presence of its soluble forms, such as ortho-silicic acid, which is present in drinking and mineral water in the range of 2 to 5 mg/L. Currently, it has been established that silicon compounds are necessary for the normal functioning of epithelial and connective tissues, to which they impart strength, elasticity, and impermeability. These properties of connective tissues, due to the presence of silicon, are important not only for the skin but also for blood vessels, where silicon is concentrated primarily in elastin and, to a lesser extent, in collagen. The amount of silicon in connective tissue dramatically drops in atherosclerosis. As a result, the robustness of artery walls is compromised by a decrease in elastin levels. Simultaneously, wall permeability increases, allowing lipids to penetrate the plasma and deposit within the blood vessels. Similar changes occur during aging, which is why atherosclerosis is particularly prevalent among the elderly. Silicon compounds actively participate in human hair and nail growth processes. The silicon deposited there chemically binds keratin macromolecules with cross-links, increasing its resistance to the action of liquids. One of the simplest and most obvious diagnostic signs of silicon deficiency in the body is brittle nails. Magnesium, iron, copper, manganese, silicon, boron, and several other micronutrients, including vitamins B6, B9 (folates), B12, C, K, carotenoids, flavonoids, Omega-3, and polyunsaturated fatty acids (PUFAs), also contribute to maintaining the health of the bone system and connective tissues. Magnesium, manganese, copper, zinc, and boron are commonly referred to as osteotropic minerals that promote the synthesis of collagen and elastin. Animal experiments have shown that silicon increases the rate of bone mineralization and calcification along with vitamin D. Furthermore, the metabolism of silicon and calcium is closely linked. For example, the aging process is associated with an imbalance between these elements, specifically a decrease in silicon content and an increase in calcium in connective tissues. Introducing silicon into the diet promotes bone tissue healing. For maximum absorption of silicon by bone tissue, vitamin K is necessary, which plays a vital role in bone mineralization through the carboxylation of osteocalcin. A deficiency of vitamin K can affect the incorporation of silicon into bone tissue. It is important to note the regulatory, personalized role of the microbiome and genome in these processes (Aguirre-Cruz *et al*., 2020; Arely *et al*., 2020; Kim *et al*., 2020; Araujo *et al*., 2021; Khatri *et al*., 2021; Santos & Duarte, 2021; Al-Atif, 2022; Song & Zhang, 2022; Farhadieh & Gianoutsos, 2023; Javadpoor & Shariati, 2023; Jugdaohsingh & Powell, 2023; Martinez-Puig *et al*., 2023; Mikhailovich *et al*., 2023; Oubari & El-Ghorab, 2023; Price *et al*., 2023; Pu *et al*., 2023; Ohara & Ito, 2024).

The water composition includes a complex of other vital mineral substances that, along with silicon, determine its therapeutic properties. Silicon and its numerous compounds play an important role in the body's metabolic reactions and are primarily necessary for the normal functioning of connective tissue (Danchin *et al*., 2024; Mendoza *et al*., 2024).

The technology for producing "Metacollagen Silicon+" substance has been developed and implemented at ArtLife's modern automated biotechnological facility, certified under ISO 22000 and GMP international standards. The innovativeness of this technology lies in the enzymatic hydrolysis of native collagen under mild processing conditions (controlled temperature and pH). The cleavage of the collagen molecule is mediated by a biological catalyst—an enzyme produced via eco-friendly microbial synthesis.

The final product and its synergists, or promoters, are meant to be used in the production of speciality nutrition and cosmetics. These products are designed to correct metabolic disorders in connective tissues (epithelium, mucous membranes, cartilage, etc.) and improve the physiological condition and aesthetic appearance of skin, hair, and nails (Çınaroğlu *et al*., 2023; Delcea *et al*., 2023; Hsiao *et al*., 2024; Rossi *et al*., 2024; Tan *et al*., 2024).

Experimental Section: Recycling of Gelatin Raw Materials

This study evaluates the feasibility of repurposing hard gelatin capsules (HGC) as raw material components, addressing both environmental and economic concerns. Research focused on the concentration of synthetic dyes in fermented HGCs, as these substances represent potential health risks (Song & Zhang, 2022; Javadpoor & Shariati, 2023; Martinez-Puig *et al*., 2023; Mikhailovich *et al*., 2023; Oubari & El-Ghorab, 2023; Skov & Jensen, 2023; Bian *et al*., 2024; Lima & Costa, 2024; Zhang & Yang, 2024).

The study objects included: HGC capsules №0 (green/transparent 340/340; green/green 564/564; red/red 1805/1805) and high-purity dyes (Brilliant Blue 85%, Carmine 85%, Copper complex of chlorophyllin 97%, and Quinoline Yellow).

Methodology: UV-Vis Spectrophotometry

Sample Preparation: Investigated solutions of fermented HGC were diluted 10–50 times with demineralized water, depending on color intensity. Demineralized water served as the blank sample. All tests were performed in duplicate (Ku *et al*., 2023; Yang *et al*., 2023; Di Fiore *et al*., 2024; Mickevičius *et al*., 2024; Kalion *et al*., 2025).

Calibration Curves: A standard dye solution (250 µg/mL) was prepared based on active dye content (QC data). Working solutions were then prepared in concentrations of 0.5–10 µg/mL (up to 20 µg/mL for carmine).

Experimental results are visualized in **Figures 1 and 2**.

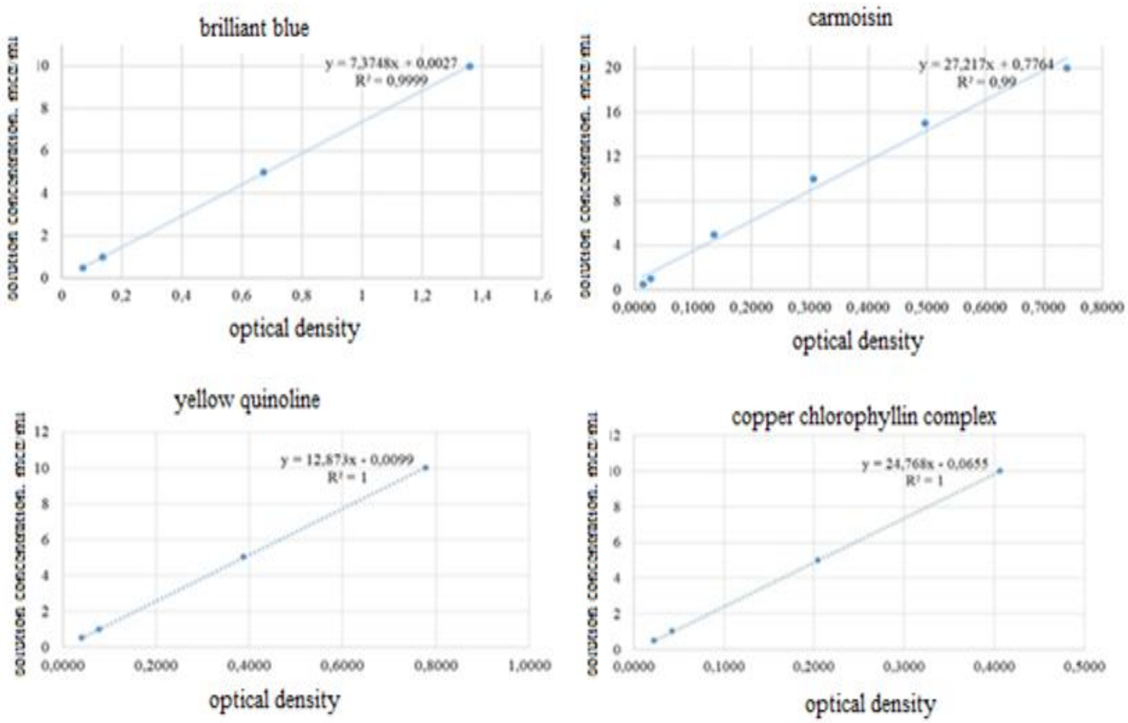

Figure 1. Calibration curves of working dye solutions

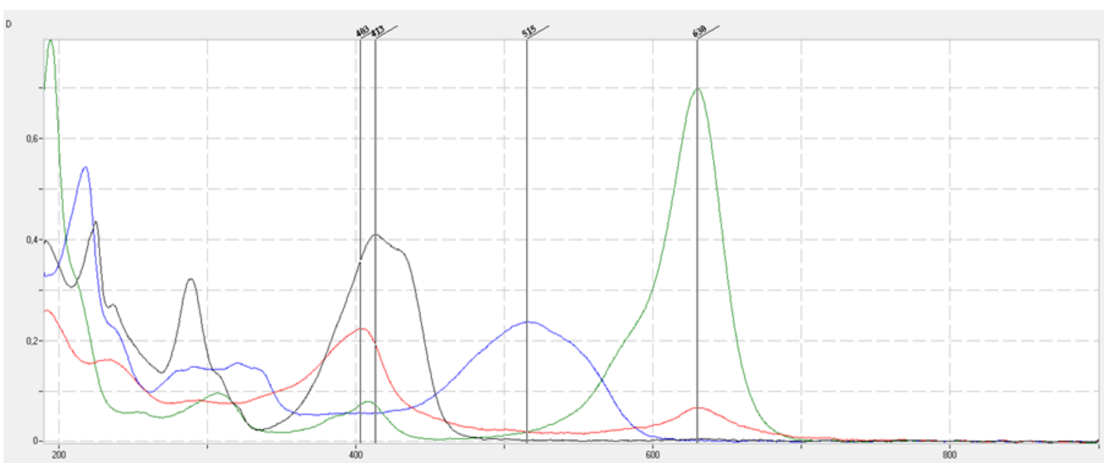

Figure 2. UV spectra of dye solutions

* Note: Blue spectrum – carmine (λmax = 515 nm); green spectrum – Brilliant Blue (λmax = 630 nm); red spectrum – copper complex of chlorophyllin (λmax = 403 nm); black spectrum – Quinoline Yellow (λmax = 413 nm).

The results of using different sorbents are presented in **Table 2**.

Table 2. Comparative table of using different sorbents (green/transparent sample, diluted 20 times)

Sorbent	Copper Complex of Chlorophyllin Content in Fermented TJK, µg/mL			
Control	698.73		205.91	
Zeolite coarse 2%	685.68	1.02 times	202.12	1.02 times
Zeolite coarse 10%	652.52	1.07 times	194.76	1.06 times
Zeolite coarse 20%	622.08	1.12 times	185.24	1.11 times
Zeolite fine 2%	630.10	1.11 times	187.54	1.10 times
Zeolite fine 10%	530.90	1.32 times	171.31	1.20 times

Sorbent	Copper Complex of Chlorophyllin Content in Fermented TJK, μg/mL	Reduction in concentration compared to the control	Brilliant Blue Content in Fermented TJK, μg/mL	Reduction in concentration compared to the control
Zeolite fine 20%	401.19	1.74 times	159.25	1.29 times
MCC 2%	655.59	1.07 times	194.45	1.06 times
MCC 10%	644.84	1.08 times	194.24	1.06 times
MCC 20%	611.55	1.14 times	185.25	1.11 times
Charcoal 2%	367.68	1.90 times	75.33	2.73 times
Charcoal 10%	171.40	4.08 times	10.78	19.10 times
Charcoal 20%	102.64	6.81 times	7.24	28.44 times

According to the data presented in **Table 1** and **Figure 2**, activated charcoal exhibits the best sorption properties, reducing the content of copper complex of chlorophyllin by 1.9-6.81 times and Brilliant Blue by 2.73-28.44 times.

According to TR TS 0.29/2012 Annex 11, the concentration of dyes in dietary supplements should not exceed 300 mg/kg of dry product. An exception is the copper complex of chlorophyllin, for which there is no strict limitation. Consequently, in a 7g product of collagen, the amount of dyes should not exceed 2.1 mg. Purification of fermented TJK with 10% or more activated charcoal satisfies this requirement. The conclusion is that for the purification of TJK from dyes, it is advisable to use activated charcoal at a concentration of 10% as a sorbent. Based on the results of the conducted studies, the possibility of using a new form of biologically active collagen for maintaining connective tissue health can be concluded. The innovative biotechnology for obtaining a new raw ingredient is positioned as a universal protein substance for the production of specialized products with defined functional properties.

Solid gelatin capsules can be used as an additional raw material source for gelatin, provided they are purified from synthetic dyes.

Conclusion

The conducted research demonstrates the high efficacy of activated charcoal (at a 10% concentration) for the purification of enzymatically hydrolyzed collagen raw material (fermented TJK) from synthetic food dyes, including the copper complex of chlorophyllin and Brilliant Blue FCF. This sorption treatment enables the reduction of dye concentrations to levels compliant with the stringent regulatory requirements of TR TS 029/2012 for dietary supplements. The resulting purified collagen protein hydrolyzate possesses significant potential as a universal functional ingredient. Its application is primarily targeted at the development of specialized food products and dietary supplements designed for the maintenance and restoration of connective tissue health. The proposed biotechnological approach not only solves the issue of decontaminating raw materials from unwanted colorants but also aligns with the principles of resource-saving and waste utilization, as it allows for the processing of secondary gelatin-containing resources, such as colored capsule shells. Thus, the study substantiates a viable technological strategy for obtaining safe, standardized protein substrates with targeted functional properties for the nutraceutical and food industries.

Acknowledgments: The authors thank the administration of the Research and Production Association «Art Life» for the opportunity to research its basis.

Conflict of interest: None

Financial support: None

Ethics statement: None

References

Aguirre-Cruz, G., León-López, A., Sepúlveda-Guzmán, V., Jinzárez-Valdez, M. T., & Ojeda-Ramírez, D. (2020). Collagen hydrolysates for skin protection: Oral administration and topical formulation. *Molecules, 25*(9), 2213. doi:10.3390/molecules25092213

Al-Atif, H. (2022). Collagen supplements for aging and wrinkles: A paradigm shift in the fields of dermatology and cosmetics. *Dermatology Practical & Conceptual, 12*(1), e2022018. doi:10.5826/dpc.1201a18

Araujo, L. A., Addor, F., & Campos, P. M. (2021). Use of silicon for skin and hair care: An approach to chemical forms available and efficacy. *Anais Brasileiros de Dermatologia, 91*(3), 331–335.

Arely, L. L., Gabriel, A. C., Enriqueta, Q. M., Jesús, B. S., & Gabriel, S. G. (2020). Hydrolyzed collagen—Sources and applications. *Molecules, 25*(18), 4031. doi:10.3390/molecules25184031

Bian, L., Wang, T., Zhang, S., Li, Y., & Yan, J. (2024). Evaluation of various adsorbents for the removal of synthetic food dyes from protein-rich solutions. *Food Chemistry, 435*, 137562. doi:10.1016/j.foodchem.2023.137562

Çınaroğlu, M., Ahlatcıoğlu, E. N., Prins, J., & Nan, M. (2023). Psychological challenges in cancer patients and the impact of cognitive behavioral therapy. *International Journal of Social Psychology Aspects of Healthcare, 3*, 21–33. doi:10.51847/ZDLdztUSsw

Danchin, A., Ng, T. W., & Turinici, G. (2024). Transmission pathways and mitigation strategies for COVID-19. *Interdisciplinary Research in Medical Sciences Special Issue, 4*(1), 1–10. doi:10.51847/p0YhQPxvkW

Delcea, C., Rad, D., Gyorgy, M., Runcan, R., Breaz, A., Gavrilă-Ardelean, M., & Bululoi, A. S. (2023). Exploring Romanian resilience: A network analysis of coping mechanisms during the COVID-19 pandemic. *International Journal of Social Psychology Aspects of Healthcare, 3*, 13–20. doi:10.51847/HgPIOyOclr

Di Fiore, A., Stellini, E., Savio, G., Rosso, S., Graiff, L., Granata, S., Monaco, C., & Meneghello, R. (2024). A review of recent literature on the handling of anterior resin-bonded cantilever restorations. *Journal of Current Research in Oral Surgery, 4*, 1–8. doi:10.51847/JcU1FD46Qw

EFSA Panel on Food Additives and Flavourings. (2021). Re-evaluation of Quinoline Yellow (E 104) as a food additive. *EFSA Journal, 19*(3), e06443.

Farhadieh, R. D., & Gianoutsos, M. (2023). Collagen kinetics and the role of silicon in wound healing and connective tissue remodeling. *Journal of Plastic, Reconstructive & Aesthetic Surgery, 82*, 145–156.

Felician, V. V., Xia, C., Chen, W. Q., Xu, H. M., & Xu, Y. J. (2021). Collagen and its derived peptides: Review of production and biological activities. *International Journal of Molecular Sciences, 22*(3), 1109. doi:10.3390/ijms22031109

Genc, S., & Ibanoglu, S. (2024). Application of fungal proteases for the production of bioactive gelatin peptides: Kinetic and functional property approach. *LWT - Food Science and Technology, 198*, 115982. doi:10.1016/j.lwt.2024.115982

Hashim, A. F., & Al-Naimi, S. (2022). Influence of silicon-rich mineral water on human bone mineral density: A longitudinal study. *Journal of Trace Elements in Medicine and Biology, 71*, 126956. doi:10.1016/j.jtemb.2022.126956

Hsiao, F. H., Chen, P. L., Ho, C. C., Ho, R. T. H., Lai, Y. M., & Wu, J. L. (2024). Exploring the impact of cognitive-behavioral therapy on anxiety disorders in children and adolescents. *International Journal of Social Psychology Aspects of Healthcare, 4*, 26–31. doi:10.51847/jcgvRFfQPM

Javadpoor, M., & Shariati, M. A. (2023). Biotechnology of gelatin recovery from pharmaceutical waste: Enzyme-assisted purification and dye removal. *Journal of Cleaner Production, 385*, 135712. doi:10.1016/j.jclepro.2022.135712

Jugdaohsingh, R., & Powell, J. J. (2023). Dietary silicon and bone health: Integrating the latest evidence-based nutrition. *Nutrients, 15*(11), 2541. doi:10.3390/nu15112541

Kalion, O. O., Stepanova, E. S., Gaziev, U. M., Prikhodko, V. R., Iazhian, M. N., Mikhailova, R. I., Askerov, A. M., & Ayubov, A. V. A. (2025). Post-surgical complications of the thyroid gland: Insights from the literature. *Interdisciplinary Research in Medical Sciences Special Issue, 5*(1), 23–28. doi:10.51847/lNIPS8K5pi

Khatri, M., Naughton, R. J., Clifford, T., Harper, L. D., & Smith, L. (2021). The effects of collagen peptide supplementation on body composition, collagen synthesis, and recovery from joint injury and exercise: A systematic review. *Amino Acids, 53*(10), 1493–1506. doi:10.1007/s00726-021-03026-8

Kim, D. U., Chung, H. C., Choi, J., Sakai, Y., & Lee, B. Y. (2020). Oral intake of low-molecular-weight collagen peptide improves hydration, elasticity, and wrinkling in human skin: A randomized, double-blind, placebo-controlled study. *Nutrients, 12*(4), 1100.

Ku, J. K., Um, I. W., Jun, M. K., & Kim, I. H. (2023). Clinical management of external apical root resorption using amniotic membrane matrix and Bio-Dentine. *Journal of Current Research in Oral Surgery, 3*, 1–5. doi:10.51847/lOSwt6Qzpv

León-López, A., Morales-Peñaloza, A., & Martínez-Juárez, V. M. (2020). Hydrolyzed collagen—Sources and applications. *Molecules, 25*(18), 4031. doi:10.3390/molecules25184031

Li, Y., & Wei, X. (2023). Effects of orthosilicic acid on collagen synthesis in human osteoblast-like cells. *Biological Trace Element Research, 201*(4), 1620–1629. doi:10.1007/s12011-022-03284-w

Lima, T., & Costa, R. (2024). Circular economy in the pharmaceutical industry: Recycling of gelatin capsule shells through advanced sorption techniques. *Waste Management, 174*, 88–97. doi:10.1016/j.wasman.2023.11.025

Martinez-Puig, D., Costa-Larrión, E., Rubio-Rodríguez, N., & Gálvez-Martín, P. (2023). Collagen supplementation: A review of its benefits on skin soreness, joint pain, and bone density. *Nutrients, 15*(4), 1026. doi:10.3390/nu15041026

Mendoza, L., Calderón, J., & Núñez, A. (2024). Epimedium and its flavonoids as multi-target anti-aging agents: A systematic review of preclinical and clinical evidence. *Interdisciplinary Research in Medical Sciences Special Issue, 4*(1), 82–95. doi:10.51847/R1tmgFZam5

Mickevičius, I., Astramskaitė, E., & Janužis, G. (2024). A systematic review of the implant success rate following immediate implant placement in infected sockets. *Journal of Current Research in Oral Surgery, 4*, 20–31. doi:10.51847/PcPJL1v1XF

Mikhailovich, P. V., Tokhiriyon, B., Vladimirovna, P. O., Vladislavovna, U. Y., & Grigorevna, C. N. (2023). Composition and potential applications of biologically active complexes. *Pharmaceutical Science and Drug Design, 3*, 47–52. doi:10.51847/bKnAn84YeH

Mohamed, M. A., & Al-Tahir, K. (2021). UV-Vis spectrophotometric determination of synthetic food dyes in pharmaceutical dosage forms using calibration curves. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 248*, 119213.

Ohara, H., & Ito, K. (2024). Bioavailability of hydroxyproline-containing peptides in human serum after oral ingestion of collagen hydrolysates. *Food Chemistry: X, 21*, 101054. doi:10.1016/j.fochx.2024.101054

Oubari, H., & El-Ghorab, A. (2023). Activated charcoal as a versatile sorbent for the removal of food colorants: Kinetic and equilibrium studies. *Biocatalysis and Agricultural Biotechnology, 47*, 102558.

Price, C. T., Koval, K. J., & Langford, J. R. (2023). Silicon: A review of its role in human health. *Journal of Bone and Mineral Research Plus, 7*(6), e10742.

Pu, S. Y., Huang, Y. L., Pu, C. M., Kang, Y. N., & Ho, T. J. (2023). Effects of oral collagen for skin anti-aging: A systematic review and meta-analysis. *Nutrients, 15*(9), 2080. doi:10.3390/nu15092080

Rahman, M., & Al-Mamun, A. (2022). Biotechnological production of fungal alkaline proteases: Advancements and industrial applications. *Journal of Biotechnology, 345*, 12–25.

Rossi, V., Galli, M., & Fontana, C. (2024). Inequality trends in childhood anemia across Ethiopian regions: Evidence from DHS 2005–2016. *International Journal of Social Psychology Aspects of Healthcare, 4*, 113–126. doi:10.51847/KtAkpk0yph

Santos, T. S., & Duarte, A. P. (2021). Collagen-based materials for nutraceutical and pharmaceutical applications: Current trends and future perspectives. *Biomaterials Advances, 129*, 112318. doi:10.1016/j.msec.2021.112318

Shariati, M. A., & Khan, M. U. (2025). Trace element enrichment in functional protein substances: Silicon integration. *Journal of Food Composition and Analysis, 137*, 106742. doi:10.1016/j.jfca.2024.106742

Skov, P. S., & Jensen, K. (2023). Risk assessment of synthetic dyes in dietary supplements: Implications for long-term health. *Food and Chemical Toxicology, 172*, 113540.

Song, H., & Zhang, S. (2022). Effects of collagen peptides from bovine bone on bone mineral density and bone metabolism in rats. *Journal of Functional Foods, 94*, 105114. doi:10.1016/j.jff.2022.105114

Tan, G. Y., Lim, W. M., & Ong, H. X. (2024). Perceived control and self-rated health from young adulthood to midlife: Findings from the longitudinal youth development study. *International Journal of Social Psychology Aspects of Healthcare, 4*, 100–112. doi:10.51847/bUYUzIFshB

Wang, L., & Chen, X. (2023). Optimization of enzymatic hydrolysis of collagen from animal by-products using Protosem C. *Bioresource Technology Reports, 22*, 101456. doi:10.1016/j.biteb.2023.101456

Yang, J., Tang, Z., Shan, Z., & Leung, Y. Y. (2023). Integrating rapid maxillary expansion and Le Fort osteotomy for esthetic rehabilitation: A clinical case report. *Journal of Current Research in Oral Surgery, 3*, 22–26. doi:10.51847/E0OEwI52jo

Zhang, L., & Yang, Y. (2024). Zeolite and microcrystalline cellulose as alternative sorbents for dye removal in the food industry: A comparative study. *Microporous and Mesoporous Materials, 365*, 112932. doi:10.1016/j.micromeso.2023.112932