BiotechIntellect, 2026, 3 (1) e9 (1-12)

https://jbiotechintel.com/index.php/biotechintel

Review Article

eISSN: 3115-7920

OPEN ACCESS

Advances in the Processing and Stabilization of Collagen-Fortified Functional Drinks

Ramona Massoud [1*], Dorsa Zakipour [2], Sepideh Saboonchi [3]

[1] Department of Food science, Iran National Standard Organization, Tehran, Iran

[2] Department of Food Science and Technology, Science and Research Branch, Islamic Azad University, Tehran, Iran

[3] Quality Assurance Department, Meiji America Inc., California, United States of America

Article history:
Received 05 March 2026
Revised 13 March 2026
Accepted 19 April 2026
Published online 22 April 2026

Keywords: *Collagen, Beverage, Enriched, Hydrolysis.*

How to cite this article: Massoud, R., Zakipour, D., Saboonchi, S. Advances in the processing and stabilization of collagen-fortified functional drinks, *BiotechIntellect,* 2026; 3(1): e9, 1-12.
https://doi.org/10.66224/BiotechIntellect.3.1.43

*corresponding author's email:
Massoud R.:
rm8059@yahoo.com,
r.massoud@tehranstandard.ir

ABSTRACT

Background and aim: Enriched foodstuffs are absorbing attention based on consumers' awareness all around the world. Collagen is one of the interests in foodstuff industry. This article reviews the collagens applications and function in beverage industry. Collagen is a great animal base protein. It plays the main role in sustaining the organs and tissues structure. Hydrolyzed collagen includes small and low-molecular-weight amino acid chains. Nowadays it is extensively consumed in beverage and food industries to ameliorate foodstuffs properties like food products stability, consistency and elasticity. In addition, it helps improving the intimacy, nutritional value and health benefits in foodstuffs. Collagen is applied as a useful food carrier, supplements, additive, coatings and film especially in beverages.
Method: A comprehensive literature search was conducted using the electronic databases Web of Science, Scopus, PubMed, Science Direct, and Google Scholar to identify relevant publications. The literature search covered studies published between 2020 and May 2025, with particular emphasis on recent publications from the last five years.
Conclusion: This paper will review the collagens applications and functions in beverage industry as well as its composition and structure. The collagen application as an enrichment agent in beverage formulation enhance the biological and nutritional value of various beverages.

What is "already known":	• Collagen is a great animal base protein. It plays the main role in sustaining the organs and tissues structure. • Hydrolyzed collagen includes small and low-molecular-weight amino acid chains.
What this article adds:	• Hydrolysed collagen is a valuable enrichment agent in beverage formulation. • Collagen enhances the biological and nutritional value of fortified beverages and exerts beneficial health effects on their consumers.

1. INTRODUCTION

Functional beverages have become one of the fast-growing parts of the global food and beverage industry, driven by increasing consumer awareness of health and wellness, and demand for convenient products that offer benefits beyond their basic nutrition [1]. Functional beverages are formulated to deliver specific physiological effects, such as supporting immune health, digestive balance, physical performance, cognitive function, and healthy aging [2]. This trend has stimulated the incorporation of diverse bioactive ingredients into beverage systems, including proteins, peptides, probiotics, vitamins, minerals, and plant-derived compounds [1].

Among these ingredients, collagen has attracted increasing attention for its important structural role in connective tissues and its potential relevance to skin health, joint function, and bone integrity [3]. In particular, hydrolyzed collagen and collagen peptides are considered promising for beverage fortification due to their improved solubility, digestibility, and suitability for liquid formulations [4]. These aspects are essential for the successful development of collagen-fortified beverages and deserve more systematic attention. Therefore, this review aims to provide a comprehensive overview of collagen fortification in functional beverages. It focuses on collagen sources and forms, the rationale for its use in beverage applications, its potential functional relevance, key formulation and stability issues, sensory considerations, and future research directions for the development of effective collagen-based beverage products.

Collagen is a family of fibrous proteins that play a fundamental role in connection and supporting tissues and structures [3]. Collagens are mainly composed of amino acids. Collagen's triple helix structure provides high mechanical strength, but in its raw form, this structure limits the solubility and ease of use in beverage systems [4]. Therefore, in the beverage industry, hydrolyzed collagen is typically used, in which the protein is broken down into smaller fragments, increasing its solubility and compatibility with formulations [5]. Figure 1. represents collagen extraction and hydrolysis sequences.

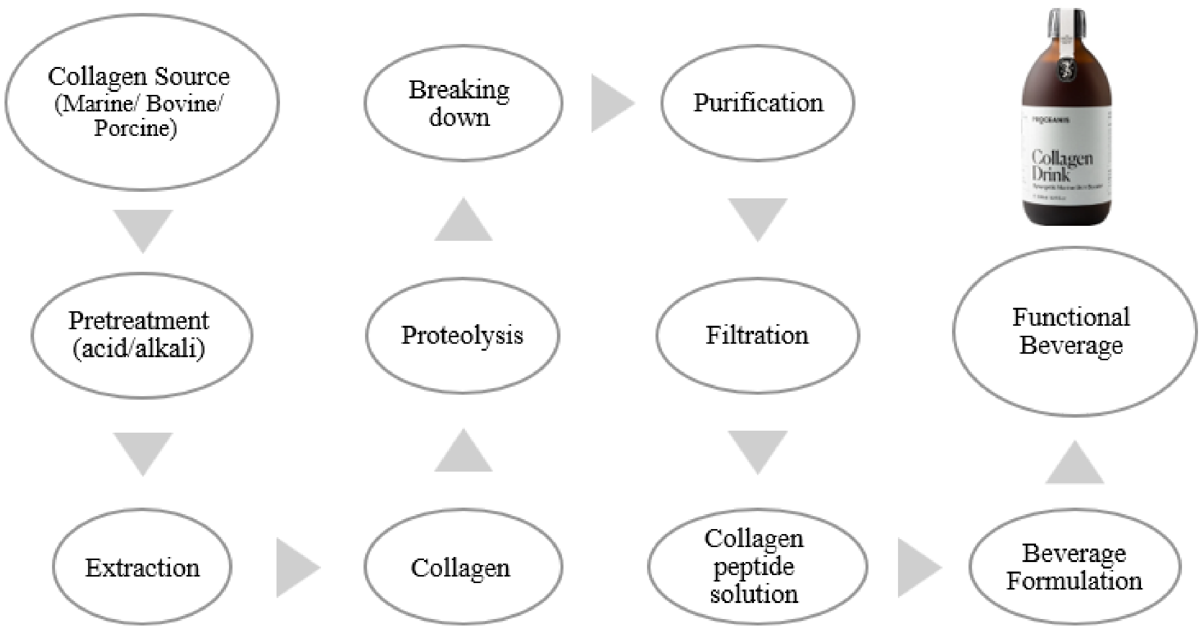

Figure 1. The schematic diagram for illustrating collagen extraction and hydrolysis

Generally, there are four main types of collagen in our body that emphasize the important role of this valuable material for our life; Type I. that makes up 90% of your body's collagen. Type II. which is found in elastic cartilage, which provides joint support. Type III. that is found in muscles, arteries and organs and Type IV. which is found in the layers of your skin [3]. Figure 2. represents the important function of these types in our body. Todays, collagen is a demand for healthy foods industry. Its productions reduce by age and diet in human body. Collagen injection is not favorable for people; thus, the clever option would be to receive collagen through the daily diet. So, collagen was thought to be added and mixed with foods and beverages [3, 4].

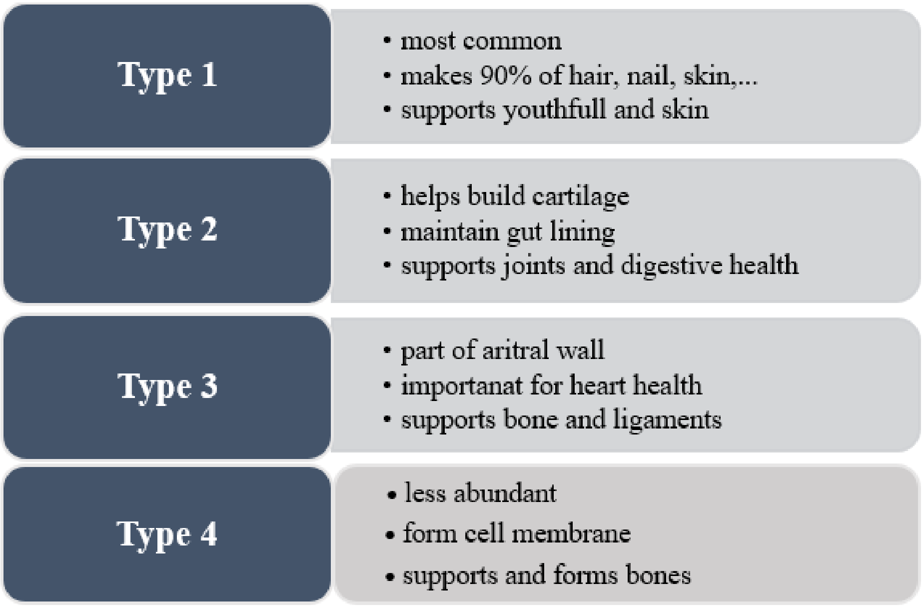

Figure 2. The key functions of collagen types in human body

2. SOURCES OF COLLAGEN

Some protein rich foods are introduced as natural collagen sources as they have the amino acids that form collagen [3]. The most important sources of this valuable substance are: meat, poultry, and fish and its quality depend on the special peptide and amino acids [4]. Collagen used in the food industry is primarily obtained from animal sources:

a. Bovine collagen

Bovine Collagen is a natural protein in many bovine species like buffalos and cows. Most Bovine Collagen is derived from cows because their connective tissues are rich of this valuable material. It is widely used due to its availability. However, safety regulations and livestock-related religious/health requirements may affect its processing [6].

b. Porcine collagen

Porcine collagen is derived from pig, particularly the bones and skin.It is especially used in supplements and protein gel products. For food use, strict purity and safety control is required [7].

c. Marine collagen

Marine or fish collagen comes from the skin of fish. It is extracted from fish skin and other marine sources. It has characteristics such as different amino acid ratios and good hydrolysis ability, and the growing consumer demand for non-mammalian options has made marine collagen more prominent [8]. As consumer awareness regarding environmental impact grows, the following sustainability and ethical sourcing in collagen production should be considered:

- Using side-streams from the fishing and meat industries (like fish skins or bones) to produce collagen, thereby reducing food waste.
- Implementing rigorous tracking systems to ensure that animal-derived collagen is sourced from farms that adhere to high welfare and environmental standards.
- Comparing the ecological footprint of marine collagen extraction versus bovine/porcine processes [3, 6].

Each of the above sources has its own advantages and disadvantages from availability, extraction method, composition to suitability for foods application [4]. Bovine and porcine are rich in fibrillar collagens (Type I: most abundant, Type II: in cartilage, Type III: in skin and tissues, and Type V: in hair and nails. In contrast, Type IV, a nonfibrillar collagen, is a major structural component of basement membranes [6]. Marine sources are rich in fibrillar Type I collagen and Type II collagen is predominant in fish cartilage especially sharks [8]. Type I collagen is also found in jellyfish and paid attention for cosmetic and medical applications [9].

3. HYDROLYZED COLLAGEN

Hydrolyzed collagen refers to peptide fragments with lower molecular weight that are produced through controlled hydrolysis of raw collagen. Table 1. shows the quantity of amino acid in hydrolyzed collagen. The native networks in the membrane of collagen are rigid and firm so, its polypeptide chain and cross-linkages would be broken by hydrolysis to show superior and special properties like higher enthalpy, better network structure, basic isoelectric point and high resistance [6, 7]. Compared with intact collagen, the hydrolyzed form has:

- higher solubility in water or aqueous solutions,
- better stability against heat and common beverage processing steps such as pasteurization,
- better suitability for clearer or semi-clear formulations [9].

Table 1. Amino acids profile in hydrolyzed collagen

Amino acid type	Amount (g/100g protein)
Glycine	22
Proline	13.5
Hydroxyproline	12
Glutamic acid	10
Alanine	8.9
Arginine	7.5
Aspartic acid	6.5
Lysine	3.5
Serene	3.2
Leucine	2.9
Valin	2.4
Threonine	2.1
Phenylalanine	2
Histidine	1

3.1. Characteristics of hydrolyzed collagen

The molecular weight and peptide distribution are so important in collagens properties, the smaller the fragments, the higher the solubility. These factors may also affect taste, mouthfeel, and the possibility of undesired chemical reactions [10]. The collagen amino acid composition is a unique factor in this protein. Collagen, apart from its origin, includes 19 amino acids having hydroxyproline which does not exist inside other proteins. Collagen's amino acid composition is specific due to the high presence of proline and glycine and the absence of cysteine [11].

3.2. Physicochemical Properties

- Thermal stability; Hydrolyzed collagen exhibits significant stability during thermal processes like pasteurization and UHT (Ultra-High

Temperature) treatment, which are essential for extending beverage shelf life [12].

- Interaction with other ingredients; The peptide fragments can interact with sugars, acids, and flavoring agents, which may influence the overall stability and sensory profile of the beverage [13].

4. PRODUCTION OF COLLAGEN-CONTAINING BEVERAGES

The production process involves several critical stages:

1. Preparation of the collagen solution dissolving the hydrolyzed collagen in a controlled medium (water or aqueous base) to ensure a homogeneous mixture.
2. Mixing and blending; incorporating other functional ingredients (vitamins, sweeteners, acids) into the collagen solution.
3. Homogenization by using high-shear mixing or homogenization to prevent sedimentation and ensure a stable colloidal system [14, 15].

Formulating a beverage with collagen requires careful consideration of solubility and stability as well as maintaining a clear or stable suspension throughout the product's shelf life [16]. Collagen increase the viscosity of the liquid, which must be balanced to meet consumer preferences for "mouthfeel" [17]. The stability of collagen peptides can be affected by the acidity of the beverage so its pH sensitivity should be considered as well [18].

4.1. Physicochemical Stability

The incorporation of collagen into functional beverage matrices necessitates a rigorous evaluation of the interplay between solution pH and thermal processing parameters. Collagen, as an amphoteric biopolymer, exhibits minimum solubility near its isoelectric point, where electrostatic repulsion between peptide chains is neutralized, potentially leading to macro-molecular aggregation and precipitation [18]. Furthermore, since most commercial functional beverages undergo thermal stabilization like pasteurization or UHT, the thermal denaturation of the collagen triple helix into gelatin must be accounted. While thermal treatment can enhance the solubility of hydrolyzed peptides, excessive heat may trigger unintended Maillard reactions with reducing sugars present in the matrix, altering both the colorimetric profile and the nutritional integrity of the bioactive components [19].

4.2. Structural & Rheological Control

Achieve a homogenous dispersion and prevent phase separation, homogenization parameters especifically pressure and number of passes, are critical in governing the particle size distribution. High-pressure homogenization (HPH) induces intense shear and cavitation, which reduces the particle diameter to the sub-micron range, thereby increasing the surface area for interaction and improving colloidal stability [18]. This process is intrinsically linked to the molecular weight distribution (MWD) of the collagen peptides; lower molecular weight fractions (typically <3 kDa) exhibit superior solubility and lower viscosity compared to higher molecular weight analogues [20]. Consequently, the rheological behavior of the resulting beverage often transitions toward a pseudoplastic (shear-thinning) model, which is essential for maintaining a fluid-like consistency during consumption while preventing sedimentation during storage [19].

4.3. Long-term Stability

The long-term shelf-life stability of collagen-fortified beverages is primarily dictated by the kinetic stability of the protein-matrix complex against sedimentation and syneresis. Over extended storage periods, even minor fluctuations in temperature or ionic strength can perturb the electrostatic equilibrium, promoting the formation of protein flocs [18]. The use of hydrocolloids or stabilizers is often required to create a structured network that increases the viscosity of the continuous phase, thereby reducing the sedimentation velocity according to Stokes' Law [20]. Monitoring the stability of the molecular weight distribution and the maintenance of a clear/uniform appearance via turbidimetry or zeta potential measurements is therefore vital for ensuring product consistency from production to end-user consumption [20].

4.4. Challenges in Formulating Collagen-containing Beverages and Solutions

Sedimentation; Over time, collagen particles may settle at the bottom. Using stabilizers (like hydrocolloids) and optimizing the particle size through advanced hydrolysis [19]. There are some

advanced stabilization techniques. Beyond basic mixing, advanced beverage science utilizes specific techniques to ensure the collagen remains in suspension. One of them is electrostatic stabilization; adjusting the pH of the beverage to a point where the collagen peptides carry similar surface charges, causing them to repel each other and preventing aggregation [17, 19]. The other is steric stabilization; the use of non-ionic surfactants or specialized polymers that create a physical barrier around the collagen particles, preventing them from clumping together [16, 19].

- Flavor and odor masking; Raw collagen may have a distinct animal smell or taste. Using high-purity hydrolyzed peptides and effective masking agents (flavors and sweeteners) [20]. To achieve the ideal balance between functionality and sensory appeal, combining collagen with other bioactive ingredients, such as hyaluronic acid or vitamin C, to enhance its biological efficacy is recommended [15]. Fine-tuning the use of hydrocolloids to achieve a better mouthfeel that recalls the traditional non-protein beverages while maintaining stability [14].

- Clarity issues; Achieving a crystal-clear beverage with high protein content is a challenge. Selecting specific molecular weight ranges of peptides would be appropriate [21].

It is stated that to produce a clear, flavored beverage containing 5g of hydrolyzed collagen per 250ml, a peptide with a molecular weight below 3,000 Daltons was required for maintaining clarity. Also, slight acidity (pH 3.5–4.0) helped in both microbial stability and keeping the collagen in a soluble state, though it required careful flavor balancing to manage the tartness [19, 20].

5. DOSAGE

Beverages would be a great option to provide a high dosage of protein. The amount of collagen added to a beverage depends on the target health claim (skin health, joint support, ...). Generally, the effective dose ranges from 2g to 10g per serving, depending on the concentration of the product [22]. For example, Athletes need higher protein intakes, nearly 1.4 to 2g of protein per kg of bodyweight per day to build and maintain their muscle mass [18]. There are some types of collagen-containing beverages:

-Ready-to-Drink (RTD): Low-calorie with functional collagen benefits.

- Functional Drinks: Combining collagen with caffeine or vitamins for lifestyle-oriented consumers.

-Protein-rich Shakes: Higher viscosity, milk-based or plant-based beverages for meal replacement or post-workout recovery.

-Tea: Collagen-fortified functional teas [22].

The integration of collagen into beverage formulations presents a growing opportunity in the functional food market. While challenges such as solubility, sensory masking, and stability exist, the use of hydrolyzed collagen and advanced formulation techniques (like homogenization and stabilizers) provides effective solutions to meet consumer demands for convenient, health-promoting drinks [16].

6. ANALYTICAL TECHNIQUES FOR QUALITY CONTROL

To ensure the precision of the formulation, the below advanced techniques are applied:

- SDS-PAGE (Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis) is used to verify the molecular weight distribution of the collagen peptides and ensure that the hydrolysis process was successful and uniform [23].

- FTIR (Fourier-Transform Infrared Spectroscopy) is used to monitor the secondary structure of collagen (specifically the characteristic amide I and II bonds) to ensure that the functional integrity of the protein remains intact after processing [23].
- HPLC (High-Performance Liquid Chromatography) is used for the precise quantification of specific amino acids, particularly hydroxyproline, which serves as a biomarker for collagen content [23].

While conventional techniques such as SDS-PAGE, FTIR, and HPLC provide fundamental insights into molecular weight, functional groups, and purity, they lack the resolution required to fully elucidate the complex conformational dynamics and polydispersity of collagen-fortified systems. To achieve a comprehensive molecular profile, several advanced analytical modalities are required:

- SEC-MALS (Size-Exclusion Chromatography coupled with Multi-Angle Light Scattering) is the gold standard for determining absolute molecular weight and polydispersity index (PDI). Unlike traditional SEC, MALS measures the light scattered by the solute at multiple angles, allowing for the direct calculation of molar mass without reliance on calibration curves [24].
- Circular Dichroism (CD) Spectroscopy is uniquely sensitive to the secondary structure of the polypeptide backbone. It is the most effective method for monitoring the transition from the highly ordered collagen triple helix to the disordered random coil (gelatinization) under varying thermal or pH stresses. By analyzing the molar ellipticity at specific wavelengths (e.g., 222 nm), researchers can quantitatively determine the stability of the helical content in the beverage matrix [24].
- Nuclear Magnetic Resonance (NMR) Spectroscopy provide unmatched resolution regarding the chemical environment of specific amino acid residues. 2D-NMR techniques (such as HSQC) are increasingly utilized to map the connectivity and spatial proximity of residues within the peptide chain. This allows for the identification of specific cleavage sites during enzymatic hydrolysis and the assessment of peptide-ingredient interactions such as collagen-polyphenol or collagen-polysaccharide complexes that may influence bioavailability [24].

6. NUTRITIONAL PROFILE AND BIOAVAILABILITY

The advantage of soft drinks containing protein is increasing as consumer demands for nutritious products that support protein intake. One of the primary reasons for adding collagen to beverages is its high bioavailability as well as health benefits and nutritional value [25]. Hydrolyzed collagen is broken down into small dipeptides and tripeptides (such as Proline-Hydroxyproline) [26]. These are absorbed more efficiently in the small intestine compared to intact proteins. These peptides act as signaling molecules that can stimulate fibroblasts (cells responsible for collagen production in the human body), particularly in the skin, joints, and bones [5, 27].

Collagen beverages with health claims, they should meet strict regulations (such as FDA in the US or EFSA in Europe). Claims like “Supports Skin Elasticity” or “Promotes Joint Health” must be proven by scientific evidence and approved by regulatory bodies [28]. The nutritional labeling must clearly state the source of collagen (Bovine-derived or Marine) and the exact amount of protein/collagen per serving. Also, about ingredient declaration, all additives used for masking flavor or stabilizing the drink must be listed in the ingredient statement [29].

As certain amino acids are sensitive to oxidation, the use of antioxidants (such as Ascorbic Acid/Vitamin C) is often integrated into the formulation to prevent degradation and off-flavors [29]. Therefore, some attentions in packaging materials seems so important for maintaining the functional properties of these functional beverage like using opaque or amber-colored PET/glass bottles to protect the product from photo-degradation, applying multi-layer packaging or specialized caps to minimize oxygen entrance, which helps prevent oxidative damage to the protein structure and ensuring that no chemical components from the plastic packaging (such as phthalates or other additives) would migrate into the beverage, which could compromise both safety and the purity of the collagen [30, 31].

7. SAFETY AND REGULATORY CONSIDERATIONS

As the commercialization of collagen-fortified beverages expands, ensuring consumer safety through rigorous control of microbiological stability and allergenicity is paramount. Microbiological safety and matrix stability and also allergenicity and immunological implications should be paid attention in this regard [4].

7.1. Microbiological Safety and Matrix Stability

Collagen-containing beverages, particularly those utilizing hydrolyzed peptides, present a unique substrate for microbial growth. The high concentration of nitrogenous compounds and the presence of residual moisture make these formulations susceptible to contamination by spoilage organisms and pathogens [4].

- Microbial Proliferation: The stability of the beverage is heavily influenced by the aw and pH while the acidic nature of many functional beverages (pH<4.6) can inhibit certain bacterial growth, it may still support the proliferation of acidophilic yeasts and molds [18, 19].

- Processing Controls: Thermal processing (e.g., Pasteurization or UHT) is essential; however, as discussed previously, excessive heat can trigger collagen denaturation and subsequent precipitation. Therefore, a critical challenge lies in optimizing thermal lethality to ensure microbial safety without compromising the structural or functional integrity of the collagen matrix [18, 20].

7.2. Allergenicity and Immunological Implications

While collagen is generally regarded as having low allergenic potential compared to major allergens like soy or dairy, its safety profile must be evaluated through the lens of its source and processing method [34].

-Source-Specific Risks: The risk of allergenicity is intrinsically linked to the origin of the collagen (bovine, porcine or marine). Marine-derived collagen, for instance, carries a potential risk for consumers with pre-existing seafood allergies, necessitating clear labeling under international food safety standards (e.g., Codex Alimentarius) [34, 35].

- Hydrolysis and Epitope Exposure: Enzymatic hydrolysis is a primary method for reducing allergenicity, as the cleavage of long polypeptide chains into smaller peptides can disrupt the conformational epitopes that trigger an immune response. However, it is crucial to ensure that the hydrolysis process is sufficiently complete to prevent the presence of intact, immunogenic protein fragments [5].

8. CONCLUSION AND FUTURE PERSPECTIVES

Collagen is a valuable ingredient in beverage industries. Hydrolyzed collagen is a nonviscous, odorless additive acting like stabilizer and emulsifier in functional drink. Hydrolyzed collagen has biological health effects as an antioxidant, antimicrobial and increased water-holding capacity agent. Collagen is worldwide accepted as an effective and functional ingredient in the food, beverage, drugs and cosmetics. It also develops improves the organoleptic properties and improves the physiochemical traits of foodstuffs and beverages. HC along with cellulose or chitosan help in preparing of scaffolds in collagen synthesis, bone and joint healthcare, wound healing, heart disorder treatment, skin care and aging reduction. As it is able to attach to vitamins and nutrients, it is easily used in various beverages. The integration of collagen into functional beverage matrices offers a significant opportunity to enhance the nutritional profile and functional properties of consumer products. This review has highlighted that the successful formulation of these beverages depends on a delicate balance of physicochemical parameters. To improve collagen-fortified beverages, future research should prioritize and the following recommendations are proposed for future product development:

- Focus on marine sources; there is a rising demand for non-mammalian and sustainable options, investing in marine collagen extraction technology is highly recommended.
- **Cross-Reactivity:** Future research must continue to investigate the potential for cross-reactivity between different collagen sources and existing food allergens to provide a definitive safety profile for highly processed functional beverages.
- Advanced flavoring technology; research into more sophisticated masking agents is needed to allow for higher protein concentrations without compromising the consumer experience.
- Consumer Awareness; marketing efforts should focus on giving information to consumers about the specific benefits of hydrolyzed peptides compared to standard proteins to justify the premium nature of these products.
- Bioavailability and Gut-Microbiome Interaction: Moving beyond simple protein content to investigate how specific collagen peptide sequences interact with the human gut microbiome and their long-term impact on metabolic health.
- Smart Packaging Integration: Developing intelligent packaging solutions that can monitor the structural integrity and freshness of the collagen-peptide complex in real-time during storage.

9. DECLARATIONS

9.1. Acknowledgments

No acknowledgments.

9.2. Authors' Contributions

RM, DZ & SS conceptualized the idea and prepared the manuscript.

9.3. Declaration of Interest

The authors of this article declared no conflict of interest.

9.4. Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

9.5. Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

9.6. Funding

This research was carried out independently with personal funding and without the financial support of any governmental or private institution or organization.

10. REFERENCES

1. Gupta A, Sanwal N, Bareen MA, Barua S, Sharma N, Olatunji OJ, Nirmal NP, Sahu JK. Trends in functional beverages: Functional ingredients, processing technologies, stability, health benefits, and consumer perspective. Food research international. 2023; 1; 170:113046. 10.1016/j.foodres.2023.113046

2. Sugajski M, Buszewska-Forajta M, Buszewski B. Functional beverages in the 21st century. Beverages. 2023; 9(1), 27. https://doi.org/10.3390/beverages9010027

3. Shenoy M, Abdul NS, Qamar Z, Al Bahri BM, Al Ghalayini KZ, Kakti A, Murad M, Fadul M, Alamri MA, Alqarni MA. Collagen structure, synthesis, and its applications: A systematic review. Cureus. 2022; 9:14(5). doi:10.7759/cureus.24856

4. Tang C, Zhou K, Zhu Y, Zhang W, Xie Y, Wang Z, Zhou H, Yang T, Zhang Q, Xu B. Collagen and its derivatives: From structure and properties to their applications in food industry. Food Hydrocolloids. 2022; 131:107748. doi.org/10.1016/j.foodhyd.2022.107748

5. Al Hajj W, Salla M, Krayem M, Khaled S, Hassan HF, El Khatib S. Hydrolyzed collagen: Exploring its applications in the food and beverage industries and assessing its impact on human health–A comprehensive review. Heliyon, 2024; 10(16), https://doi.org/10.1016/j.heliyon.2024.e36433

6. O'Grady JE, Bordon DM. Global regulatory registration requirements for collagen-based combination products: points to consider. Advanced drug delivery reviews. 2003; 28:55(12):1699-721. https://doi.org/10.1016/j.addr.2003.08.006

7. Hu YT, Tu ZC, Liu GX, Peng CY, Zhang P, Xie WM, Yang LY, Chen Y, Hu ZZ, Sha XM. Enzymatic hydrolysis affected the antioxidant activity and traceability identification of porcine collagen peptides. Food Chemistry. 2026; 15: 148451. 10.1016/j.foodchem.2026.148451

8. Shaik MI, Rahman SH, Yusri AS, Ismail-Fitry MR. Kumar NS. Sarbon NM. A review on the processing technique, physicochemical, and bioactive properties of marine collagen. Journal of Food Science. 2024; 89(9): 5205-29. doi:10.1111/1750-3841.17273

9. Zülli F, & P H. Hydrolyzed Collagen—Sources and Applications. Molecules. 2019; 24(22): 4031. doi.org/10.3390/molecules24224031

10. Kisling A, Lust RM, Katwa LC. What is the role of peptide fragments of collagen I and IV in health and disease?Life sciences. 2019; 228:30-4. 10.1016/j.lfs.2019.04.042

11. Gauza-Włodarczyk M, Kubisz L, Włodarczyk D. Amino acid composition in determination of collagen origin and assessment of physical factors effects. International journal of biological macromolecules. 2017; 104:987-91. 10.1016/j.ijbiomac.2017.07.013

12. Dille MJ, Haug IJ, Draget KI. Gelatin and collagen. In: Handbook of hydrocolloids 2021 Woodhead Publishing.Kozlowska, J., et al. Collagen as a functional ingredient in food: A review of recent advancements. 2021. pp.:1073-1097. doi.org/10.1146/annurev-food-031414-111800

13. Cui P, Shao T, Liu W, Li M, Yu M, Zhao W, Song Y, Ding Y, Liu J. Advanced review on type II collagen and peptide: preparation, functional activities and food industry application. Critical Reviews in Food Science and Nutrition. 2024; 64(30):11302-19. doi.org/10.1080/10408398.2023.2236699

14. Sae-Leaw T, Aluko RE, Chantakun K, Benjakul S. Physicochemical, antioxidant and sensory properties of ready-to-drink chrysanthemum tea fortified with hydrolyzed collagen from salmon scale ossein. Journal of Aquatic Food Product Technology. 2021; 30(9):1159-72. doi.org/10.1080/10498850.2021.1974632

15. Marete EN, Jacquier JC, O'Riordan D. Feverfew as a source of bioactives for functional foods: Storage stability in model beverages. Journal of Functional Foods. 2011; 3(1):38-43. doi.org/10.1016/j.jff.2011.01.004

16. Gautieri A, Vesentini S, Redaelli A, Buehler MJ. Viscoelastic properties of model segments of collagen molecules. Matrix Biology. 2012; 31(2):141-9. 10.1016/j.matbio.2011.11.005

17. Varga-Tóth A, Németh C, Dalmadi I, Csurka T, Csorba R, Elayan M, Enkhbold M, Hidas K, Friedrich LF. Investigation of the effects of bovine collagen peptides and mixed berries on rheological properties and biological activity of egg white-based beverage via central composite design. Frontiers in Nutrition. 2023; 9:1011553. doi.org/10.3389/fnut.2022.1011553

18. Santana RC, Perrechil FA, Sato AC, Cunha RL. Emulsifying properties of collagen fibers: Effect of pH, protein concentration and homogenization pressure. Food Hydrocolloids. 2011; 25(4):604-12. doi.org/10.1016/j.foodhyd.2010.07.018

19. Zhang Y, Zhang Y, Liu X, Huang L, Chen Z, Cheng J. Influence of hydrolysis behaviour and microfluidisation on the functionality and structural properties of collagen hydrolysates. Food Chemistry. 2017; 15; 227: 211-8. 10.1016/j.foodchem.2017.01.049

20. Bai M, Wang N, Zhang M, Zhao Z, Yu J, She W, Obadina AO, Zhao Y, Li S, Wu H, Zhao T. Deep eutectic solvent-mediated extraction of collagen peptides from sturgeon skin: Molecular-weight control and mechanistic insights. Food Chemistry: X. 2026; 37:104078. doi.org/10.1016/j.fochx.2026.104078

21. Steele C. Collagen: a review of clinical use and efficacy. Nutritional Medicine Reviews. 2022;1(2):12-36. pureencapsulations.ca/sites/default/files/2023-07/11.

22. Bilek SE, Bayram SK. Fruit juice drink production containing hydrolyzed collagen. Journal of functional foods. 2015; 14:562-9. doi.org/10.1016/j.jff.2015.02.024

23. Kržišnik N, Kurent E, Roškar R. A comprehensive analytical approach for quality control of collagen in food supplements. Marine drugs. 2024; 22(10):435. doi.org/10.3390/md22100435

24. Gao J, Jia L, Guo Z, Xu L, Fan D, Zhang G. Qualitative and Quantitative Analysis Method of Recombinant Collagen in Complex Matrix. Separations. 2024; 26;11(12):339. https://doi.org/10.3390/separations11120339

25. León-López A, Morales-Peñaloza A, Martínez-Juárez VM, Vargas-Torres A, Zeugolis DI, Aguirre-Álvarez G. Hydrolyzed collagen—sources and applications. Molecules. 2019; 24(22):4031. doi.org/10.3390/molecules24224031

26. Dautkanova D, Kazhymurat A, Dautkanov N, Ussembayeva Z, Mussayeva S. Development of a functional instant drink using soy isolate and collagen hydrolysate. Caspian Journal of Environmental Sciences. 2025; 23(5):1241-51. doi:10.22124/cjes.2025.8857

27. de Miranda RB, Weimer P, Rossi RC. Effects of hydrolyzed collagen supplementation on skin aging: a systematic review and meta-analysis. International Journal of Dermatology. 2021;60(12):1449-61. doi.org/10.1111/ijd.15518Digital Object Identifier

28. Shan F, Liu L, Li L, Wang W, Bi Y, Li M. Management, safety, and efficacy evaluation of nutraceutical and functional food: A global perspective. Comprehensive Reviews in Food Science and Food Safety. 2025; 24(4):70222. doi.org/10.1111/1541-4337.70222

29. Fisher GJ, Quan T, Purohit T, Shao Y, Cho MK, He T, Varani J, Kang S, Voorhees JJ. Collagen fragmentation promotes oxidative stress and elevates matrix metalloproteinase-1 in fibroblasts in aged human skin. The American journal of pathology. 2009; 174(1):101-14. doi.org/10.2353/ajpath.2009.080599

30. Marangoni Júnior L, Rodrigues PR, da Silva RG, Vieira RP, Alves RM. Sustainable packaging films composed of sodium alginate and hydrolyzed collagen: preparation and characterization. Food and Bioprocess Technology. 2021;14(12):2336-46. doi.org/10.1016/j.foodhyd.2011.12.003.

31. Ezati P, Khan A, Bhattacharya T, Zaitoon A, Zhang W, Roy S, Rhim JW, Lim LT. Recent advances in collagen and collagen-based packaging materials: a review. ACS Food Science & Technology. 2025; 5(5):1767-84. doi.org/10.1021/acsfoodscitech.4c00938

32. Szopa K, Znamirowska-Piotrowska A, Szajnar K, Pawlos M. Effect of collagen types, bacterial strains and storage duration on the quality of probiotic fermented sheep's milk. Molecules. 2022; 8;27(9):3028. https://doi.org/10.3390/molecules27093028

33. Mejía-Calvo I, López-Juárez LE, Vázquez-Leyva S, López-Morales CA, Montoya-Escutia D, Merlos Rivera PG, Herbert-Pucheta JE, Zepeda-Vallejo LG, Velasco-Velázquez M, Pavón L, Pérez-Tapia SM. Quality attributes of partially hydrolyzed collagen in a liquid formulation used for skin care. Journal of

Cosmetic Dermatology. 2021;20(1):150-8. https://doi.org/10.1111/jocd.13439

34. Soedarini B, Octavia S ET. A literature review of allergen properties in fish collagen and its derivative products. Jurnal Pengolahan Hasil Perikanan Indonesia. 2024 Aug 23;27(8):719-39. https://journal.ipb.ac.id/index.php/jphpi/issue/vi...

35. World Health Organization. Risk Assessment of Food Allergens. Part 1: Review and validation of Codex Alimentarius priority allergen list through risk assessment: Meeting report.