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Rheological properties of mucin from the snail *Achatina fulica*

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Abstract. This article examines the functional role of various thickeners in cosmetic formulations. The study of their rheological properties and behaviour in aqueous solutions is essential for the development of stable and effective products within the skincare and dermocosmetic sectors. This study aimed to investigate the behaviour of a novel, naturally derived cosmetic ingredient – mucin from the snail *Achatina fulica* – in an aqueous medium under varying pH conditions, and to provide practical recommendations for its use. The study included an analysis of the physicochemical properties, mechanisms of action, and functional characteristics of five key thickeners: guar gum, Aristoflex, sodium alginate, gelatine, and carbomer. Their technological advantages, limitations, and applications in cosmetic products were outlined. In an aqueous solution, mucin exhibited a high swelling capacity: within 90 minutes, its volume increased ninefold, which is comparable to the performance of other hydrocolloids examined. The structural viscosity of mucin solutions within the concentration range of 0.1%-10.0% is characterised by a non-linear increase. A marked rise in viscosity is observed at concentrations between 1.5% and 3.0%, which is attributed to the attainment of maximum intermolecular interaction strength. It was found that the viscoelastic properties of aqueous mucin solutions depend not only on concentration but also on the pH of the medium, with mucin exhibiting non-Newtonian behaviour. Maximum structural stability was observed within the pH range of 5.0 to 6.5, where the structural viscosity of a 3.0% solution reached 127 mPa·s. Recommendations have been proposed regarding the inclusion of snail mucin in cosmetic formulations, taking into account the rheological and sensory characteristics of the final product. These insights may prove valuable to researchers and practitioners in the cosmetics industry

Keywords: thickeners; concentration; structure formation; medium acidity; cosmetic products

Introduction

Snail mucin, known for its moisturising, regenerative, and anti-inflammatory properties, is increasingly being used as a functional ingredient in skincare products. However, its behaviour as a thickener and stabiliser under varying conditions remains insufficiently studied. In particular, little is known about the impact of mucin on the rheological properties of low-concentration solutions, which is important for controlling the consistency and stability of cosmetic formulations. In both cosmetic and biomedical fields, a range of polymolecular substances are employed to stabilise emulsions and suspensions, regulate viscosity, and control the release of active ingredients. These include polymers and hydrogels capable of forming stable structures that help preserve the efficacy of active compounds over time. Given the molecular structure of mucin, its ability to swell in aqueous solutions may be anticipated, suggesting

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a potential influence on the consistency, stability, sensory characteristics, and bioavailability of final products.

The theoretical aspect of such research is linked to the development of polymer solution theory, while the practical focus lies in establishing empirical relationships between elastoplastic properties and technological parameters. From a practical standpoint, appropriate rheological properties are crucial in influencing consumer choice. For this reason, manufacturers often adjust the composition of the aqueous phase in cosmetic products by incorporating thickeners or structuring agents. Thickeners (structuring agents) are key ingredients used to increase viscosity and ensure the stability of dispersed systems in cosmetic formulations. Their application not only improves the rheological performance but also enhances the aesthetic qualities of the final product.

According to a study by E. Sikora (2019), hydrocolloids used as thickeners in cosmetics can be classified into the following categories: natural polymers – hydrocolloids of plant origin (mucilage, gums, resins, starch, dextrins, pectins, protein-based substances), and those of animal origin (polypeptides such as gelatine, casein, whey proteins, etc.); biosynthetic hydrocolloids – produced by microorganisms, e.g. dextran, xanthan gum; synthetic polymers – chemically or physically modified derivatives of cellulose, starch, or polyacrylic acid; inorganic compounds – minerals from the aluminosilicate group (such as bentonite), and colloidal silica.

P. Himashree *et al.* (2019) identified the primary functions of thickeners as moisture retention, structural modification, and the alteration of flow properties. Factors such as temperature, shear, pH, and ionic strength influence the functionality of these thickeners and must be carefully optimised by manufacturers during the production process. Proper optimisation of these conditions is critical to ensuring the stability and efficacy of the final products. Among the most effective thickeners are modified starches and proteins, used either individually or in combination with exudates, seed gums, seaweed extracts, and microbial polysaccharides.

The search for texturising agents and new combinations of known substances continues. For example, L. Rigano *et al.* (2019) proposed the use of *Caesalpinia spinosa* gum – a plant-derived polysaccharide obtained by milling the endosperm of *Caesalpinia spinosa* seeds – and investigated its rheological behaviour, compatibility with common cosmetic ingredients, and its use as a thickener in various types of cosmetic formulations. G. Tafuro *et al*. (2021) explored binary associations of sclerotium gum with iota-carrageenan, which imparted high viscosity, elasticity, and resilience to the system, as well as combinations of locust bean gum and pectin, which influenced the viscoelastic properties of the system, contributing to high adhesiveness and cohesiveness.

In the food industry, thickeners have traditionally been used to increase viscosity, stabilise texture, and regulate the rheological properties of products. For instance, R. Shkaraputa *et al.* (2024) highlighted the important role of structuring agents in developing the texture and consistency of food products for vegans. These agents were used to replace collagen, preserve density and create a meatlike texture in meat substitutes, as well as to enhance the flavour and aroma of spices and aromatic plant-based additives.

There is also experience in applying polymolecular substances to achieve the desired rheological properties in technical systems. For example, R. Shilton *et al*. (2025) demonstrated that incorporating xanthan gum into alkali-activated material blends improved buildability during 3D printing and allowed the material to maintain its shape (structural integrity) while remaining flowable under stress – enabling pumping and extrusion.

A deep understanding of the mechanisms behind the viscoelastic behaviour of hydrocolloids enables the optimisation of technological processes, the prediction of system behaviour during storage and use, and the development of new materials with tailored functional properties. This study aimed to investigate the rheological behaviour of *Achatina fulica* mucin in aqueous media under varying pH conditions, in order to provide practical recommendations for its use in cosmetic formulations.

Materials and Methods

The following ingredients were investigated: natural plant-based thickeners – guar and xanthan gum, sodium alginate, the animal-derived thickener mucin, and the synthetic agents Aristoflex and carbomer. Aqueous solutions of these gelling agents were prepared at concentrations ranging from 0.1% to 10.0%. To prepare the solutions, accurately weighed samples were dissolved in bidistilled water under stirring and made up to a final volume of 100 mL.

The characteristics of the selected gelling agents are outlined below. Mucin, a relatively novel and under-researched thickener derived from the mucus of giant snails (*Achatina fulica*), lacks a fixed chemical formula. It is a high-molecular-weight glycoprotein composed of a protein backbone with numerous attached oligosaccharide chains. The protein portion of mucins is rich in serine (Ser), threonine (Thr), and proline (Pro), while the carbohydrate side chains are linked to serine and threonine residues via O-glycosidic bonds (Ahmad *et al.,* 2021). The principal carbohydrates include N-acetylglucosamine (GlcNAc), galactose (Gal), fucose (Fuc), and sialic acid (Neu5Ac). Mucin exhibits high biocompatibility as it is a key component of mucus, which plays lubricating, protective, and barrier roles, particularly within the digestive, respiratory, and reproductive systems (Momoh *et al.,* 2019). Its inclusion in skincare products supports effective tissue repair, promotes healing of damaged skin, and offers protection against irritation – features of particular relevance in therapeutic and cosmetic creams designed for sensitive skin.

The general formula of the glycoprotein part (simplified):

$$\text{(Ser/Thr)–O–(GalNAc)–(Gal)–(Neu5Ac)}, \qquad (1)$$

where Ser/Thr is the amino acid residue (serine or threonine); O is the amino acid residue (serine or threonine);

GalNAc is the N-acetylgalactosamine; Gal is the galactose; Neu5Ac is the sialic acid.

Guar gum is a natural hydrocolloid that forms viscous colloidal solutions in aqueous media. It is extracted from the seeds of the guar plant (*Cyamopsis tetragonoloba*), a leguminous crop cultivated primarily in India and Pakistan. A notable advantage of guar gum in cosmetic formulations is its additional moisturising and conditioning properties (Mudgil *et al.,* 2014). Chemically, it is a polymer composed of mannose and galactose residues. Aristoflex is a polyacrylate derivative with high thickening efficiency at low concentrations. It demonstrates excellent compatibility with surfactants across a wide pH range (Baskar *et al.*, 2002). Its primary drawback is a relatively high production cost compared to natural alternatives. It is used in gels, serums, and lightweight emulsions for skincare. Sodium alginate is a natural polysaccharide that forms stable gels in the presence of calcium cations. It is derived from brown algae (Phaeophyceae) such as *Laminaria*, *Macrocystis*, and *Fucus*. Alginate is noted for its high hydrophilicity and moisture retention capacity; however, it is highly sensitive to changes in pH (Lee & Mooney, 2012). Gelatine is a protein obtained from collagen through the hydrolysis of animal bones, cartilage, and skin, most commonly from cattle or pigs. This natural protein polymer forms thermoreversible gels upon cooling (Chandra *et al.*, 2023); however, as of 2025, its use in cosmetic formulations is limited due to the rising popularity of vegan cosmetics.

Carbomer is a synthetic polymer based on acrylic acid, known for its high thickening efficiency in aqueous systems. It is synthesised by polymerising acrylic acid or its salts in the presence of initiators and stabilisers in an aqueous solution. The resulting polymer is then neutralised (typically with alkalis), enabling it to form gels. Although effective at low concentrations, carbomer is sensitive to electrolytes and must be neutralised to achieve optimal performance (Khanlari & Dubé, 2015).

The degree of polymer swelling was calculated as the difference between the initial polymer volume and the swollen polymer volume using the formula:

$$\acute{\alpha} = \frac{V - V_0}{V_0}, \tag{2}$$

where V_0 is the initial volume of the polymer, and V is the volume of the swollen polymer.

Viscosity was measured using an Ostwald viscometer, which operates by recording the flow rate of a liquid through a capillary tube of known radius and length. Density was determined using a pycnometer, with bidistilled water used as the reference liquid. The pH values were measured using a portable electronic pH meter with a measurement range of 0.00-14.

Results and Discussion

The effectiveness of thickeners can be indirectly assessed by examining their swelling capacity. The gel formation process is quantitatively characterised by the degree and rate of swelling. When preparing hydrogels with a low concentration of thickener, the gelation is primarily determined by the cooling phase and does not follow the kinetics of a first-order chemical reaction. Therefore, the rheological properties of the tested gelling agents were compared based on the degree of swelling, expressed as the amount of liquid absorbed per unit mass or volume of polymer, as illustrated in Figure 1.

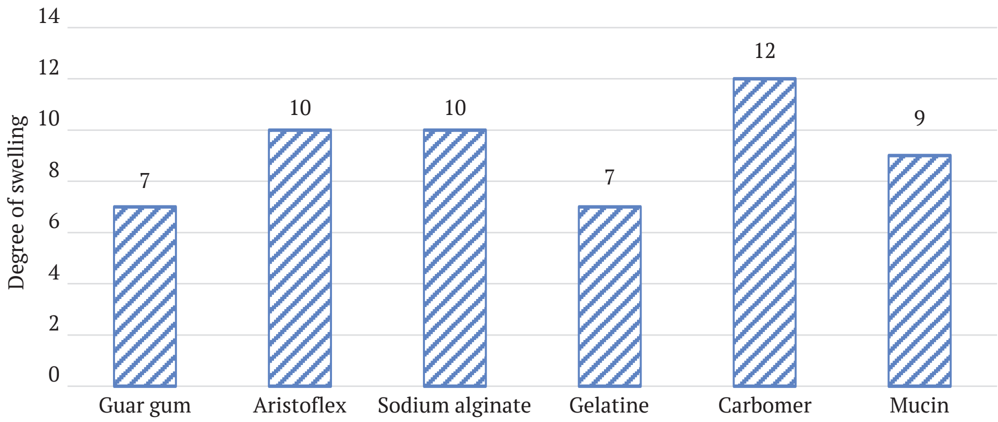


Figure 1. *Degree of swelling after 90 minutes of observation*

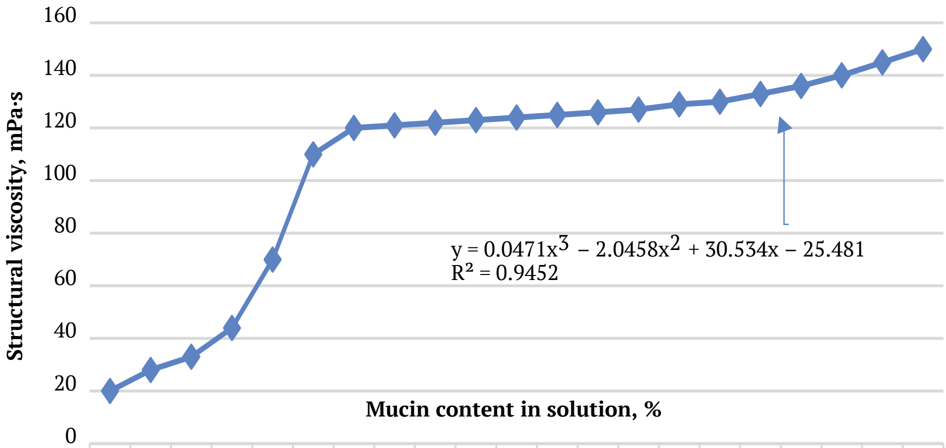
Source: *compiled by the authors*

Given that the molecular size of all the analysed thickeners is close to that of macromolecules, their swelling capacities are relatively similar. In terms of swelling ability, the synthetic thickeners Aristoflex and carbomer demonstrated superior performance, with sodium alginate performing nearly as well. Gelatine exhibited moderate swelling, producing an opaque gel with a yellowish hue. The volume of guar gum increased sevenfold, while mucin showed a ninefold increase. As the polymer chains of the substances under investigation are flexible, complete dissolution by the end of the 90-minute experiment is expected.

Observation of the swelling process revealed that the dissolution of polymers differs significantly from the dissolution mechanism of low-molecular-weight compounds. In the latter case, molecules diffuse into the solvent. In contrast, when polymers dissolve, the polymer itself effectively acts as the solvent, while the low-molecular-weight liquid plays the role of the solute. This means that water molecules penetrate the polymer structure. Initially, they fill the spaces between macromolecular chains, resulting in a reduction in the overall volume of the system. Subsequently, the intermolecular bonds within the polymer weaken, allowing the solvent to penetrate further into the structure. As a result, the polymer's volume increases, although the total volume of the system remains constant.

According to F.K. Metze *et al.* (2023), the process of one-sided penetration of solvent molecules into a polymer is referred to as swelling. It has been observed that the studied hydrocolloids are prone to unlimited swelling, which gradually transitions into dissolution, forming a homogeneous single-phase system. Overall, the behaviour of these substances in aqueous solution can be explained by the diffusion of molecules into the solvent and the formation of systems resembling colloids. Notably, all the resulting gels scatter sunlight, exhibiting the Tyndall effect characteristic of colloidal systems. In terms of swelling capacity, snail mucin performs on par with more well-known cosmetic thickeners and can be considered a competitive alternative.

As cosmetic formulations typically require low-concentration thickener solutions, the minimum gelation concentration of mucin was investigated. The effect of mucin concentration on the viscosity of aqueous solutions is presented graphically in Figure 2. Sample preparation included a swelling stage, as described in the previous experiment. The thickener concentration ranged from 0.1% to 10%, which falls within the recommended cosmetic usage levels.



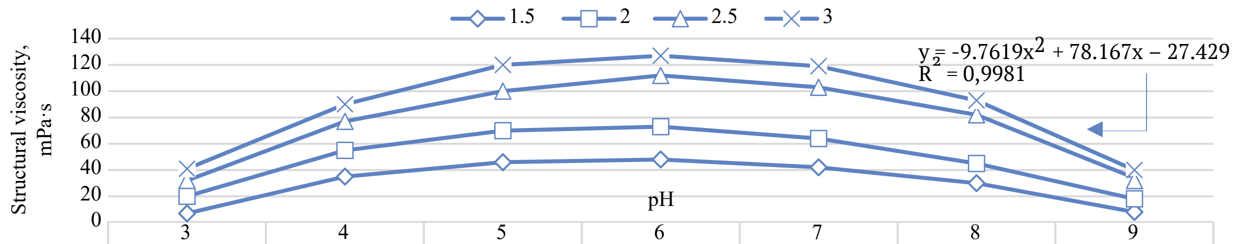
	0.1	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.9	10
Viscosity	20	28	33	44	70	110	120	121	122	123	124	125	126	127	129	130	133	136	140	145	150

Figure 2. *Mucin gelation concentration in aqueous solutions*

Source: *compiled by the authors*

Figure 2 showed the relationship between the structural viscosity of the solution and the concentration of the mucin thickener. Within the concentration range of 1.5% to 3.0%, a sharp increase in viscosity is observed, indicating the formation of a structured system held together by intermolecular forces. Beyond this range, further increases in mucin concentration result in a linear rise in viscosity, which is characteristic of truly soluble substances. The trend line follows a thirddegree polynomial equation. Based on the obtained results, the recommended dosage of mucin in cosmetic formulations may be narrowed to a maximum of 3.0%.

As established in the studies of B. Yuan *et al.* (2019) and several Ukrainian researchers, including O.P. Nekrasov & B.A. Veretenchenko (2018), the viscosity of colloidal solutions is influenced by the pH of the medium. Acidity is a critical characteristic of cosmetic products, affecting both the selection of active ingredients and the overall efficacy of the formulation. Research conducted by O. Peredriy (2022) outlined regulatory safety requirements for cosmetic products within EU countries, which is particularly relevant when incorporating novel bioactive ingredients such as mucin derived from the snail *Achatina fulica*. The researcher emphasised that the inclusion of such components requires strict adherence to enhanced safety assessment procedures, monitoring of nanomaterials, and the provision of accurate product information. According to the Technical Regulations for Cosmetic Products (2021), products containing herbal extracts, fruit acids, and their derivatives must maintain a permissible pH range of 3.0-9.0. Therefore, the behaviour of mucin within this pH range was investigated. The relationship between the viscosity of mucin solution and pH value is presented in Figure 3.



	3	4	5	6	7	8	9
1.5	7	35	46	48	42	30	8
2	20	55	70	73	64	45	18
2.5	32	77	100	112	103	82	34
3	41	90	120	127	119	93	40

***Figure 3**. Dependence of mucin solution viscosity on pH*

***Source:** compiled by the authors*

Figure 3 illustrated that the viscosity of aqueous mucin solutions is significantly influenced by the pH of the medium. Viscosity fluctuations are observed across the entire investigated pH range, regardless of solution concentration. Based on the overall trend, a further decrease in viscosity can be anticipated as the pH deviates from neutrality. For all tested concentrations, peak viscosity is observed within the mildly acidic pH range of 5.0 to 6.5. This range should therefore be recommended as optimal, as it yields the maximum achievable viscosity. It was also noted that the general trend in structural formation within the solution remains consistent with the findings shown in Figure 2: higher mucin concentrations correspond to increased viscosity throughout the full pH range of 3.0 to 9.0. However, this difference becomes less pronounced at strongly acidic or strongly alkaline pH levels. All obtained viscosity profiles follow a similar pattern and can be described using a second-degree polynomial equation (one example of which is shown as the trendline equation of the obtained curves in Figure 3).

The results obtained can be explained by the behaviour of macromolecules in media with varying concentrations of H^+ and OH^- ions. The observed increase in viscosity is likely due to the unfolding of the molecule as a result of electrostatic repulsion, leading to a change in its conformation. In strongly acidic or strongly alkaline environments, the molecule tends to coil back into a compact structure, causing a reduction in viscosity. This occurs because an increase in ionic strength reduces electrostatic repulsion between charged groups within the molecule, thereby stabilising the compact, folded structure of the polymer.

These patterns align well with findings from other researchers studying the behaviour of lowconcentration solutions of polymolecular substances in water. For instance, K.O. Lebedeva *et al.* (2022) investigated gelation and the rheological behaviour of hydrogels based on agar-agar at concentrations ranging from 25% to 50%, highlighting the critical role of temperature and cooling rate in the formation of spatial polymer networks. O.M. Kaminsky *et al.* (2024) worked with elastic gelatine-based gels at a 15% concentration, which exhibited high mechanical stability and biocompatibility, making them suitable for applications in medicine and biotechnology. S.S. Stepanov & V.M. Mokrosnop (2021) studied the properties of sulphated polysaccharides from algae, which, owing to the presence of numerous hydroxyl and sulphated groups, form stable hydrogels and three-dimensional networks capable of retaining large volumes of water without losing elasticity. Thus, research into gelation has primarily focused on high-concentration solutions of conventional food thickeners, while non-food-grade polymeric substances remain less extensively studied. Notably, polymeric substances intended for cosmetic or pharmacological use continue to be a relatively underexplored area.

O.V. Maikovych *et al.* (2021) described the conditions for preparing a composite hydrogel based on polyacrylamide and gelatine with polypropylene microfibre. The authors identified the minimum component concentrations, as well as the temperature and pH ranges, required for the formation of a polyacrylamide-gelatine hydrogel. Their findings demonstrated that hydrogel formation occurs during the structuring reaction within a pH range of 2 to 4. Notably, no hydrogel was formed at pH values above 4, while at pH levels below 2, the samples were heterogeneous. This was attributed to the simultaneous hydrolysis of functional groups occurring alongside the structuring process. Therefore, the formation of the structured network is critically dependent on the acidity of the medium, and the stability of the resulting polymer network decreases outside the specified range. The pH range identified as optimal for the studied system lies in the strongly acidic region, whereas mucin has been shown to be more effective in mildly acidic conditions.

The study by K. Belinska & T. Marusei (2022) provided insights into the swelling kinetics of extrudates, which may contribute to a deeper understanding of biopolymer behaviour in various media. The research established that the rate and extent of swelling are dependent on the type of dispersing medium – an important factor in assessing the hydration properties of mucin, which in turn influence its rheological characteristics and potential application in cosmetic or pharmaceutical systems. K. Joyner *et al.* (2019) reported the development of a mucin-based hydrogel produced via a thiol-based cross-linking strategy. Mucin hydrogels with viscoelastic properties resembling those of natural mucus were synthesised using a cross-linking reagent (the specific compound was not disclosed). The authors found that the rate of gel formation could be effectively controlled by adjusting the ratio of mucin to cross-linker. Structural formation within the gel network was attributed to hydrogen bonding and disulphide linkages. This approach enables the mechanical properties of the material to be tailored according to its intended use – ranging from soft coatings to structured gels suitable for the delivery of bioactive compounds. The findings support the fabrication of viscoelastic microstructures with physiologically relevant properties based on highly concentrated mucin solutions.

The present study focused on low-concentration solutions suitable for practical use in cosmetic manufacturing and cosmetic chemistry. Based on the rheological properties and stability of *Achatina fulica* mucin in aqueous media, its suitability for inclusion in various types of cosmetic formulations was established. The results support the following recommended concentrations of snail mucin in cosmetic products: in facial creams and serums – 1.0%-3.0%; in masks and patches – 2.0%3.0%; in toners and essences – 0.5%-1.0%; and in cleansing products – 0.1%-0.5%. These concentrations allow for the development of conventional textures while ensuring minimal use of the valuable active ingredient. The inclusion of mucin is not advised in acid-based peels, gels, or neutralising sprays, nor products intended for carboxytherapy, as these formulations typically involve strongly acidic environments in which the gel-forming ability of mucin is reduced. The findings of this study thus contribute to a broader understanding of the potential uses of *Achatina fulica* mucin in cosmetic compositions. It has been demonstrated that, even at low concentrations, mucin exhibits stable rheological properties suitable for the formulation of a variety of product types.

Conclusions

Thickeners are essential components of cosmetic products, as they determine the rheological properties, stability, and sensory characteristics of the final formulation. Their use enables control over viscosity, enhances texture, and ensures the even distribution of active ingredients. As the properties of thickeners vary depending on their chemical structure and origin, it is important to select them rationally per the specific requirements of the cosmetic formula. The optimal choice of thickener depends on the desired rheological behaviour and the final texture of the product. Natural thickeners, such as guar gum, sodium alginate, and gelatine, are suitable for the formulation of environmentally friendly cosmetics. Meanwhile, synthetic thickeners like Aristoflex and carbomer offer high stability and allow for the creation of unique textures. Optimal product performance can often be achieved through the combination of different types of thickeners within a single formulation. The rheological behaviour of a cosmetic thickener – mucin from *Achatina fulica*. In an aqueous solution, mucin demonstrated the ability to swell, increasing its volume ninefold over a 90-minute observation period, showing a swelling capacity comparable to that of other commonly studied hydrocolloids. The structural viscosity of mucin solutions at concentrations ranging from 0.1% to 10.0% increased non-linearly across the entire studied range. A marked rise in viscosity was observed between 1.5% and 3.0%, corresponding to the point of maximum intermolecular interaction. It was established that the viscoelastic properties of mucin depend not only on concentration but also on the pH of the medium, with the substance exhibiting non-Newtonian behaviour. The structure reached maximum stability within a pH range of 5.0 to 6.5, where structural viscosity values were recorded as follows: 48 mPa · s for the 1.5% solution; 73 mPa · s for the 2.0% solution; 112 mPa · s for the 2.5% solution; and 127 mPa · s for the 3.0% solution. These findings should be taken into account when developing cosmetic formulations. The results obtained may be applied to optimise the composition of cosmetic and pharmaceutical products containing mucin, and also provide a basis for further research into its functional properties in biomaterials and medical applications.

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Conflict of Interest

None.

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Реологічні властивості муцину равлика *Achatina fulica*

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Анотація. У статті розглянуто функціональну роль ряду згущувачів у косметичних рецептурах. Дослідження їх реологічних властивостей та поведінки у водних розчинах є важливим для розробки стабільних і ефективних косметичних засобів в сегментах доглядової та дерматокосметичної продукції. Метою було вивчити поведінку нового косметичного інгредієнту природного походження – муцину равлика *Achatina fulica* – у водному середовищі зі змінним значенням pH та надати практичні рекомендації по його застосуванню. Проведено аналіз фізико-хімічних властивостей, механізмів дії та функціональних характеристик п'яти ключових згущувачів: гуарової камеді, Арістофлексу, альгінату натрію, желатину та Карбомеру. Описано їхні технологічні переваги, обмеження та сфери застосування в косметичних засобах. У водному розчині муцин продемонстрував високу здатність до набухання: впродовж 90 хвилин спостереження його об'єм збільшився у 9 разів, що є співставним із показниками інших досліджуваних гідроколоїдів. Структурна в'язкість розчинів муцину в концентраційному діапазоні 0,1-10,0 % характеризується нелінійним зростанням. Значне підвищення в'язкості реєструється при концентраціях від 1,5 % до 3,0 %, що обумовлено досягненням максимальної сили міжмолекулярних взаємодій. Встановлено, що в'язкісно-пружні характеристики водних розчинів муцину залежать не лише від концентрації, а також від pH середовища, коли муцин демонстрував неньютонівську поведінку. Максимальна стабільність його структури спостерігалася в діапазоні pH від 5,0 до 6,5, коли структурна в'язкість 3,0 %-го розчину досягає 127 мПа · с. Запропоновано рекомендації щодо вмісту равликового муцину в косметичних складах з урахуванням реологічних та сенсорних характеристик кінцевого продукту, які будуть корисні для науковців та фахівців-практиків косметичної індустрії

Ключові слова: згущувачі; концентрація; структуроутворення; кислотність середовища; косметичні засоби