REVIEW

APPLICATIONS OF CHITOSAN IN THE PREPARATION OF CARE COSMETICS

Julia Rypińska[1], Justyna Kozłowska[1,a,*]

[1] – Faculty of Chemistry, Nicolaus Copernicus University in Toruń, Gagarina 7 Str., 87-100 Toruń, Poland
[a] – ORCID: 0000-0002-2482-339X
[*]corresponding author: justynak@umk.pl

Abstract
Cosmetics manufacturers are becoming increasingly interested in chitosan due to its interesting biological and technical properties, which include being a natural conditioning and moisturising agent for the skin and hair. Indeed, according to the European Commission database CosIng (https://ec.europa.eu/growth/tools-databases/cosing/details/ 75065), the functions assigned to chitosan in cosmetics are film forming and hair fixing. This review discusses the unique physicochemical and functional properties of chitosan, the market for chitosan-based skin care and hair products and recent advances. Finally, future perspectives regarding applications of this biopolymer in cosmetics are discussed.

Keywords: *chitosan, cosmetics, moisturising, conditioning, skin, hair*

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1. Introduction

The modern cosmetics industry places great emphasis on producing products that are safe for humans and the environment [1, 2]. Legal regulations regarding the introduction of cosmetics to the European Union (EU) market are very restrictive and regulate the process at every stage [3]. Much attention has been paid to environmental pollution, to which the cosmetics industry also contributes. The ingredients approved for use in cosmetics are constantly monitored to minimise the adverse effects of these products on the environment. Recently, there has been a trend towards reducing ingredients used in cosmetics formulations, and some environmentally unfriendly ingredients have been banned for use in the production of cosmetics. For example, microplastics have been gradually removed from cosmetics and are not recommended as abrasives in scrubs, toothpaste or other product formulas [4, 5]. Cosmetics producers prefer to use raw materials of natural origin, including plant, animal and mineral raw materials. Natural ingredients are also sought after by consumers. The growing awareness of cosmetics users encourages them to analyse the composition of the product before purchasing it. A modern consumer pays attention not only to the presence of natural active ingredients, such as plant extracts, vitamins, plant oils and essential oils, but also to other ingredients that make up the product, including emulsifiers, thickeners, preservatives and humectants [6–8].

Polymers, especially those of natural origin, are a very interesting group of compounds used to produce many conventional and novel cosmetics. Natural polymers, also named biopolymers, represent a specific class of renewable and biodegradable materials that are important in high-performance production [9]. Among biopolymers, proteins and polysaccharides are the main ingredients used in cosmetics applications. Collagen [10, 11], gelatine [12], elastin [13], silk [14] and keratin [15] are very common in modern cosmetics used for skin, body, hair and oral care; as make-up; and as decorative products. Polysaccharides are also popular; the most frequently used in the cosmetics industry are sodium alginate [16], xanthan gum [17], starch [18], hyaluronic acid [19, 20], cellulose [21], carrageenan [22], pectin [23] and chitin and its derivatives [24, 25]. Biopolymers are safe for the skin, biocompatible, environmentally friendly, non-toxic and widely available, so their use in cosmetics has continued to grow [26]. In cosmetics formulations, biopolymers are utilised as rheology modifiers, thickeners, emulsifiers, hydrators, destabilisers, film formers and fixatives [27]. Of note, the presence of biopolymers affects the properties and effects of cosmetics. One of the most characteristic features of biopolymers and their derivatives is moisturising properties. They hydrate skin, reduce transepidermal water loss (TEWL) and act as a barrier due to film formation on the skin surface [28].

Chitin is a natural biopolymer that occurs in the shells of crabs, shrimp and insects and in the cell walls of fungi and algae [29]. However, chitin is more useful when transformed into chitosan following a partial deacetylation process under alkaline conditions [30]. Chitosan and its derivatives (e.g. carboxymethyl chitosan and hydroxypropyl chitosan) have physicochemical and biological properties that allow for their application in a broad range of hygiene products and personal care cosmetics [31].

Cosmetics ingredients present on the EU market are regulated by Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products. Chitin and chitosan, as animal by-products, are not on the list of substances that are prohibited (Annex II – List of substances prohibited in cosmetic products) or allowed with restrictions (Annex III – List of substances which cosmetic products must not contain except subject to the restrictions laid down) for use in cosmetics [3]. Moreover, Annex 2 of Regulation (EC) No 1223/2009 in position 419 bans the use of substances that meet the definition of Category 1 and 2 materials as defined in Articles 4 and 5, respectively, of Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002, and ingredients derived there from. This regulation establishes the health rules concerning animal by-products not intended for human consumption, including animal by-products used in cosmetics. Thus, animal by-products are allowed in cosmetics manufacturing if they comply with purity, safety and hygiene requirements. This review summarises the existing knowledge about chitosan as a cosmetics ingredient.

2. Physicochemical Properties of Chitosan

Chitosan (Figure 1) is a linear polysaccharide derived from chitin (Figure 2), which is found in crustaceans and insects. To obtain chitosan, chitin must undergo deacetylation, which results in the removal of acetyl groups and repeating units of glucosamine and *N*-acetylglucosamine [32, 33]. Its molar mass varies based on the source and processing, influencing viscosity, mechanical properties and biological activities. Chitosan with a higher molecular mass from a few thousand to over a hundred thousand Daltons is linked to enhanced bioadhesive properties [34–36]. The degree of deacetylation, expressed as a percentage, signifies the extent of chitin conversion to chitosan, impacting solubility, charge density and bioactivity. Higher deacetylation increases the positive charge and improves solubility in acidic conditions [37]. Chitosan is initially insoluble in water at neutral pH due to positively charged amino groups but becomes soluble in acidic conditions (pH < 6.5) upon protonation, enabling interaction with negatively charged molecules [38, 39]. Chitosan's ability to form gels and to swell in aqueous solutions is utilised in drug delivery and hydrogel preparations [40]. It exhibits thermal stability up to a certain temperature, making it applicable in processes involving elevated temperatures. With absorption and adsorption capabilities, especially for heavy metals and dyes, chitosan contributes to environmental remediation and wastewater treatment [41]. Overall, the diverse physicochemical properties of chitosan make it a versatile material with applications in various fields.

Chitosan faces some limitations in its solubility depending on its molecular structure and pKa [42]. Chitosan and chitin have been defined and differentiated by their different solubility profiles. Chitin is insoluble in organic solvents, whereas chitosan has limited solubility: it is soluble in all acidic organic solvents like acetic acid (1%–3%), tartaric acid and citric acid (4%) at pH < 6.5. This limited solubility of chitosan is due to its highly crystalline structure, which enhances inter- and intra-molecular hydrogen bonding. However, tailoring chitosan based on chemical modifications and derivatisation makes it soluble in a wide range of pHs. Chitosan shows a strong cationic character when added to acidic solutions due to the presence of a primary amine group on its backbone. These positively charged groups interact with counter ions (e.g. drugs, excipients, ions and polymers) [43].

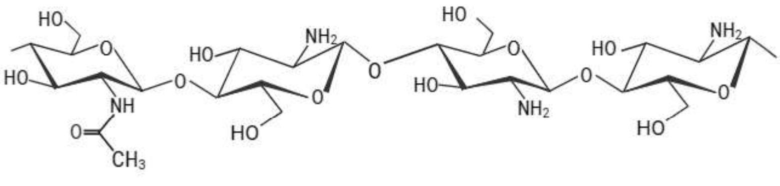

Figure 1. The chemical structure of chitosan.

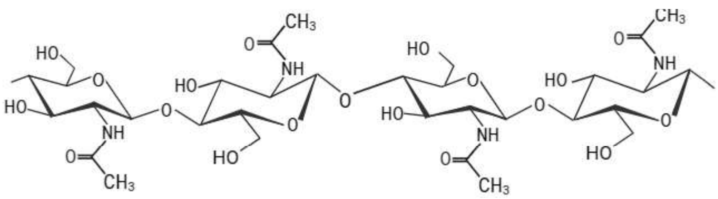

Figure 2. The chemical structure of chitin.

3. Functional Properties of Chitosan

Many physicochemical properties, such as solubility and charge, are pH dependent. Chitosan is positively charged in acidic conditions and suitable for applications like drug delivery and wound healing. Its low toxicity further enhances its suitability for medical use, ensuring safety in pharmaceuticals, medical devices and food preservation applications [44]. Chitosan's lack of immunogenicity is a significant advantage in scenarios where unwanted immune responses need to be minimised, particularly in the fields of tissue engineering and drug delivery [45]. The material's robust mechanical properties, including its film-forming ability and structural strength, enable its use to create films, membranes and scaffolds. These applications find relevance in areas such as wound dressings and controlled-release drug delivery. Chitosan's distinctive gel-forming ability and swelling capability are harnessed in the development of gel-based formulations and hydrogels, providing solutions for controlled-release drug-delivery systems and other biomedical applications [40]. The bioadhesive properties of chitosan allow it to adhere effectively to biological surfaces [46]. This adhesive ability is particularly valuable in drug-delivery systems requiring targeted and prolonged release. Inherent antimicrobial activity adds another dimension to chitosan's functionality. Its ability to inhibit the growth of bacteria and fungi makes it a sought-after material in wound dressings, food packaging and antimicrobial coatings. Chitosan's metal ion chelation capacity, facilitated by its amino and hydroxyl functional groups, renders it effective to remove heavy metals from water, contributing to environmental remediation efforts. Moreover, chitosan's absorption and adsorption capabilities, especially for heavy metals and dyes, find applications in environmental remediation and wastewater treatment, showcasing its multifaceted functional properties [47]. Figure 3 shows the many applications of chitosan, and Table 1 lists some of the functional properties of chitosan.

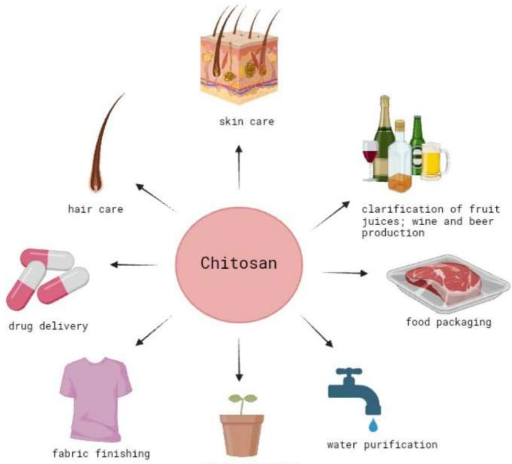

Figure 3. The major applications of chitosan.

Table 1. A list of some of the functional properties of chitosan.

Property	Reference
Biodegradability	[48]
Biocompatibility	[48, 49]
Antimicrobial activity	[50]
Antioxidant	[51]
Mucoadhesive	[52]
Antihyperglycaemic	[53]
Antibacterial and antifungal	[54, 55]
Wound healing	[56–59]
Antitumoural	[60]
Anti-inflammatory	[61]
Absorption and permeation enhancer	[62]
Film-forming ability	[63, 64]
Chelation	[65]
Drug delivery	[59, 52, 66–69]
Haemostatic effect	[70, 71]
Immunostimulation	[72]
Ability to absorb and retain water	[73, 74]

4. Chitosan in Skin Care Cosmetics

With its high molar mass, chitosan is widely utilised in the cosmetics industry to produce skin moisturisers, offering a cost-effective alternative to hyaluronic acid. It is incorporated into creams, lotions, anti-ageing cosmetics, nail care items and cleansing materials. The antimicrobial and antifungal properties of chitosan make it suitable for oral care products, such as toothpaste and mouthwashes, contributing to fresh breath and preventing plaque formation [75].

Chitosan can form a protective film on the skin's surface upon application and thus act as a barrier, reducing TEWL and enhancing skin hydration. Additionally, its hydrophilic nature attracts and binds water molecules, promoting skin moisturisation. Chitosan fills in fine lines and wrinkles upon application on the skin surface, improving their appearance for a temporary flawless and smooth effect [76]. Figure 4 shows the effect of chitosan applications on the skin.

Due to its cationic nature, chitosan exhibits inherent antibacterial properties. The positively charged amino groups interact with microbial cell membranes, disrupting their integrity and leading to microbial death or growth inhibition. This mechanism renders chitosan effective against acne-causing bacteria and other microbes, making it suitable for skincare products designed for acne-prone skin. Chitosan's multifaceted actions on skin physiology contribute to its anti-ageing effects. As a potent antioxidant, chitosan scavenges free radicals generated by environmental stressors, protecting skin cells from oxidative damage and premature ageing. Furthermore, chitosan stimulates collagen synthesis in the dermis, promoting skin elasticity and firmness. Its ability to induce cell proliferation and tissue regeneration aids in repairing damaged skin, further enhancing its anti-ageing effects. In wound healing, chitosan deposition on the skin surface creates a network structure, stimulating collagen synthesis and supporting tissue regeneration, displaying biocompatibility, biodegradability and antibacterial properties. Its gentle exfoliating properties aid in removing dead skin cells, ensuring a smoother complexion and facilitating wound healing [56, 77, 78].

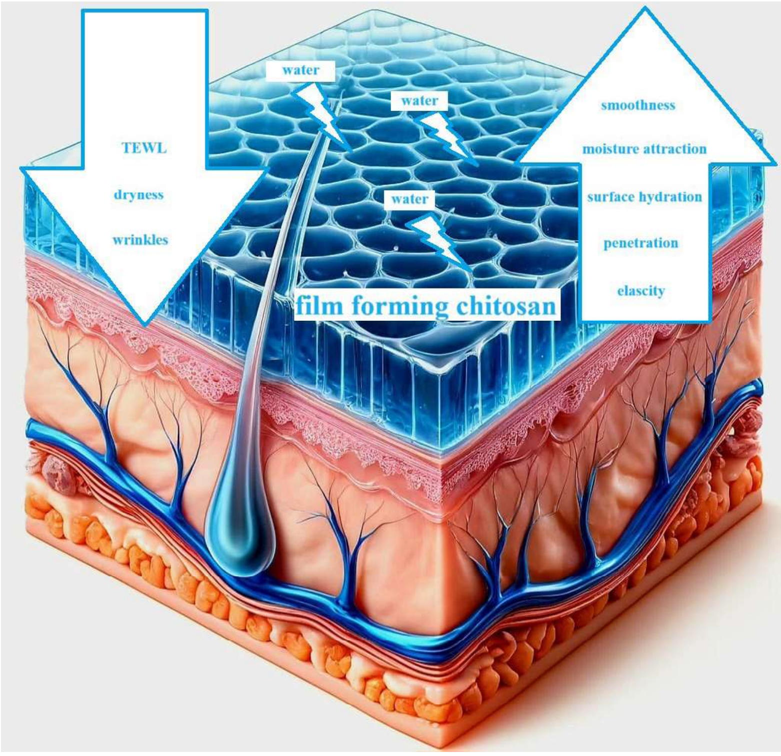

Figure 4. The effects of chitosan application to the skin surface.

Chitosan gel particles, with their moisturising properties, are adept at encapsulating hydrophilic cosmetics ingredients and penetrating the dermis for effective dermal delivery. Chitosan may have some ultraviolet-absorbing properties, making it a potential ingredient in sunscreens. Its potential as a sunscreen relies on its specific attributes, including the source, molar mass and degree of deacetylation. Although there has been insufficient research on how chitosan's characteristics influence its effectiveness as a sunscreen, applying a hybrid system film on the skin surface is a viable approach to mitigate the effects of ultraviolet (UV) radiation exposure. While it is not a replacement for dedicated sun protection ingredients, it can offer additional benefits and contribute to the overall formulation [79]. Chitosan's anti-inflammatory properties make it suitable for skincare products designed for sensitive skin. Moreover, research has shown a significant reduction in sebum levels after using cosmetics formulations containing chitosan, attributed to its ability to form complexes with sebum and thus hindering its accumulation on the skin's surface [76, 80].

Several brands use chitosan in their skin care cosmetics products [81]. Table 2 shows some commercially available skin care products with chitosan listed as an ingredient.

Table 2. Some examples of commercially available skin care cosmetics that contain chitosan [81].

Product	Manufacturer	Application
Under Eye Collagen 24k Gold Anti-Aging Eye Masks	Arlega (United States)	Mask
Intense Formula Day to Night Moisturiser	Mirabella (United States)	Facial moisturiser/ treatment
Moisturizing Hand Sanitizer, Uplifting Lemongrass	Babington Soap Co. (United Kingdom)	Hand sanitiser
Environmental Shield Essential – C Cleanser	Murad (United States)	Facial cleanser
Clarifying Cream Cleanser	Murad (United States)	Facial cleanser
High Amplify Wonder Boost	Matrix (United States)	Styling mousse/foam
Ultimate Miracle Worker Night Multi Rejuvenating Nighttime, Serum in Cream	Philosophy (United States)	Facial moisturiser/ treatment

5. Chitosan in Hair Care Cosmetics

With its positively charged amino groups, chitosan interacts with the negatively charged components of the hair, forming a complex. This interaction creates an elastic film on the hair surface, enhancing its softness, smoothness and mechanical strength. The film-forming ability of chitosan is attributed to its high molar mass and biopolymer structure, which allow it to adhere to the hair shaft and to provide structural support [76].

Chitosan's film-forming properties establish a protective layer on the hair shaft, reducing mechanical damage, such as breakage and split ends. By reinforcing the hair structure, chitosan helps to improve hair texture and resilience. Additionally, the film formed by chitosan adds thickness and volume to individual hair strands, enhancing the overall appearance and volume of hair. Its hydrophilic nature enables it to attract and retain moisture within the hair shaft, preventing excessive drying and maintaining optimal hydration levels. This moisture retention property softens the hair and reduces frizz by smoothing the hair cuticle and minimising static electricity. Chitosan's conditioning properties stem from its ability to form a protective film on the hair surface, smoothing out roughness and imparting a glossy finish. This film also helps to seal the hair cuticle, preventing moisture loss and enhancing the hair's overall texture and appearance [75, 76].

Chitosan's antimicrobial properties contribute to scalp health by inhibiting the growth of microorganisms, thus reducing the risk of scalp conditions such as dandruff [82]. Additionally, the protective film formed by chitosan on the hair surface helps to retain hair colour by minimising colour fading due to environmental factors such as UV radiation and washing. Chitosan's film-forming ability aids in detangling hair by reducing friction between hair strands, making combing easier and minimising breakage [83]. Furthermore, chitosan's potential to promote tissue repair is beneficial for addressing damaged hair, as it helps to strengthen the hair structure and improve overall hair health. In styling products like gels and mousses, chitosan's film-forming properties provide a flexible hold and structure to the hair, allowing for the creation of defined hairstyles. This film also helps to protect the hair from environmental stressors and maintain the desired hairstyle throughout the day [76].

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Product	Manufacturer	Application
Don't Despair, Repair Super Moisture Conditioner	Briogeo (United States)	Conditioner
Hair Care Don't Despair Repair! Super Moisture Conditioner	Briogeo (United States)	Conditioner
Instant Volume Volumizing Spray Gel	Aussie (United States)	Styling gel/ lotion
High Amplify Wonder Boost	Matrix (United States)	Styling mousse/foam
Instant Lift Volumizing Mousse	Kristin Ess (United States)	Styling mousse/foam
One Signature Shampoo with Avocado Oil + Castor Oil	Kristin Ess (United States)	Shampoo
Moisture Rich Curl Conditioner for Dry Damaged Curly + Wavy Hair	Kristin Ess (United States)	Conditioner
Touchable Hold Spray Gel, Scent Notes of Lily	Herbal Essences (United States)	Styling gel/ lotion
Pro-V Volume and Body Anti Frizz Hair Mousse	Pantene (Hong Kong)	Styling mousse/foam
Overnight Hair Mask	Orlando Pita Play (United States)	Hair treatment/ serum
Weightless Shine Working Hair Serum	Kristin Ess (United States)	Hair treatment/ serum
Curl Enhancer	Living Proof (United States)	Hair styling aide

6. Prospects and Challenges of Chitosan in Cosmetics Applications

According to contemporary global cosmetics trends, it is necessary to develop and obtain environmentally friendly cosmetics in terms of the product itself and the packaging. Care for the environment and the growing ecological awareness of consumers have required manufacturers to change the formulas of conventional cosmetics. Indeed, the shift from using ingredients from petrochemical sources to ingredients with a more ecological profile has been observed for a long time [1, 8]. Chitosan and its derivatives, which combine valuable physicochemical and biological qualities such as biocompatibility, biodegradability, non-toxicity, antibacterial activity and film-forming capabilities, are promising ingredients in this new trend in the cosmetics market. Chitosan is particularly helpful for preparing hair care formulations due to its electrostatic interaction capabilities with negatively charged substrates [24, 76]. So, it is an appropriate ingredient for treating damaged hair because it forms polymeric films that help condition hair. Moreover, chitosan is an ideal component for moisturising and anti-ageing skincare products due to its ability to create films, providing water while preventing dehydration. For this reason, chitosan can be found in face, hand and body creams. Moreover, it is also an ingredient in deodorising products; dental care products; and coloured cosmetics such as lipstick, eye shadow and nail polish [84, 85].

A significant limitation related to the use of biopolymers, including chitosan, in the cosmetics industry is associated with the need to standardise and optimise chitosan isolation and purification on a large scale. Generally, it is highly challenging to obtain a biopolymer with sufficient purity and source reliability [24]. Chitosan isolated from different sources may have different physicochemical and biological properties, which constitutes a significant difficulty in the production of cosmetics. When changing the supplier of chitosan, the manufacturer cannot be sure that it will obtain a batch of the cosmetics with repeatable properties. The method of obtaining and purifying this polysaccharide also results in the relatively high price of this raw material as a cosmetics ingredient [86].

There has recently been a growing aversion among consumers towards animal-derived cosmetics ingredients because they can give rise to irritative or allergic reactions [87]. Moreover, many cosmetics producers have limited the use of raw materials of animal origin in the formulation of cosmetics due to the spread of animal diseases, such as bovine spongiform encephalopathy (BSE), widely referred to as ‘mad cow disease’, transmissible spongiform encephalopathy (TSE) and avian influenza (bird flu). Many cosmetics ingredients have been replaced by similar substances extracted from plants or of a biotechnological origin. In the case of chitosan, there has been an increase in interest in obtaining it from mushrooms for cosmetics purposes, especially in the production of increasingly popular vegan cosmetics. These products are created primarily without animal suffering, with ethical standards (cruelty free) and with respect for the entire ecosystem, emphasising the defence of biodiversity [88].

Chitosan has been widely used in biotechnology, agriculture, medicine and pharmacy, wastewater treatment, food and cosmetics despite its poor solubility. Its solubility can be improved by modifying its functional hydroxyl, amino and acetamide groups, which can form various new derivatives with improved physicochemical properties [38, 89]. According to the CosIng database (https://ec.europa.eu/growth/tools-databases/cosing/details/74825), chitosan derivatives are increasingly being used in the design of modern cosmetics preparations – for example, carboxymethyl chitosan as a film-forming, gel-forming and viscosity-controlling agent (https://ec.europa.eu/growth/tools-databases/cosing/details/74825). A very interesting example of modifying chitosan for cosmetics applications is adding hydrophobic moieties to its backbone. This modified chitosan is much more amphiphilic than the parent biopolymer, thus expanding its utility in cosmetics applications. The uses of *N*-alkylated or *N*-acylated chitosans with diverse degrees of substitution and hydrophobicity include, among others, mascara, moisturising creams, wrinkle-reducing products, shampoos, conditioners, blemish concealers and controlled-release matrices for fragrance [90]. Another example of innovative applications of chitosan and chitin are bioactive, biodegradable chitosan films containing chitin nanofibrils developed for face masks [91, 92]. Moreover, chitosan has been used to design nanoparticles for skin delivery. Chitosan nanoparticles can deliver the active and cosmetics components through the skin and can be used as a cosmetics delivery system [93, 94]. Even though chitosan is not as popular in the cosmetics industry as other biopolymers, interest in this polysaccharide as a cosmetics ingredient continues to grow. Thus, the use of this polysaccharide paves the way for a potential future in developing novel cosmetics formulations.

7. Conclusions

Natural polymers are ingredients that manufacturers use eagerly because they fulfil some of the main requirements of the green cosmetics industry. Consumers are increasingly paying attention to the composition of cosmetics and want them to be as natural as possible. Chitosan is not a particularly popular ingredient in cosmetics compared with other biopolymers, which means that the valuable properties of this polymer have not yet been fully exploited in the cosmetics industry. Perhaps the popularity of this ingredient will increase in the future. Inconveniences associated with introducing it into cosmetics formulations could be eliminated due to the possibility of modifying the properties of chitosan thanks to the presence of functional groups. Indeed, distributors of cosmetics ingredients already offer several chitosan derivatives, such as carboxymethyl chitosan, hydroxyethyl chitosan and chitosan lactate.

8. References

[1] Martins AM, Marto JM; (2023) A sustainable life cycle for cosmetics: from design and development to post-use phase. Sustain Chem Pharm 35, 101178. **DOI:**10.1016/j.scp.2023.101178

[2] Amberg N, Fogarassy C; (2019) Green Consumer Behavior in the Cosmetics Market. Resour 8(3), 137. **DOI:**10.3390/resources8030137

[3] European Parliament Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on Cosmetic Products Off. J. Eur. Union (2009)

[4] Lim HY, Kwon KH; (2023) Sustainable Assessment of the Environmental Activities of Major Cosmetics and Personal Care Companies. Sustainability 15, 13286. **DOI:**10.3390/su151813286

[5] European Chemicals Agency. ECHA's Proposed Restriction. Available online: https://echa.europa.eu/hot-topics/microplastics (accessed on 8 July 2023)

[6] Faria-Silva C, Ascenso A, Costa AM, Marto J, Carvalheiro M, Ribeiro HM, Simões S; (2020) Feeding the skin: a new trend in food and cosmetics convergence. Trends Food Sci Technol 95, 21–32. **DOI:**10.1016/j.tifs.2019.11.015

[7] Guzmán E, Lucia A; (2021) Essential Oils and Their Individual Components in Cosmetic Products. Cosmetics 8, 114. **DOI:**10.3390/cosmetics8040114

[8] Rocca R, Acerbi F, Fumagalli L, Taisch M; (2022) Sustainability paradigm in the cosmetics industry: state of the art. Cleaner Waste Systems 3, 100057. **DOI:**10.1016/j.clwas.2022.100057

[9] Mendoza-Muñoz N, Leyva-Gómez G, Piñón-Segundo E, Zambrano-Zaragoza ML, Quintanar-Guerrero D, Del Prado Audelo ML, Urbán-Morlán Z; (2023) Trends in biopolymer science applied to cosmetics. Int J Cosmet Sci 45, 699–724. **DOI:**10.1111/ics.12880

[10] Avila Rodríguez MI, Rodríguez Barroso LG, Sánchez ML; (2018) Collagen: a review on its sources and potential cosmetic applications. J Cosmet Dermatol 17(1), 20–26. **DOI:**10.1111/jocd.12450

[11] Amnuaikit T, Shankar R, Benjakul S; (2022) Hydrolyzed Fish Collagen Serum from By-Product of Food Industry: Cosmetic Product Formulation and Facial Skin Evaluation. Sustainability 14, 16553. **DOI:**10.3390/su142416553

[12] Al-Nimry S, Dayah AA, Hasan I, Daghmash R; (2021) Cosmetic, Biomedical and Pharmaceutical Applications of Fish Gelatin/Hydrolysates. Mar Drugs 19(3), 145. **DOI:**10.3390/md19030145

[13] Kamaruzaman N, Yusop SM; (2021) Determination of stability of cosmetic formulations incorporated with water-soluble elastin isolated from poultry. J King Saud Univ Sci 33, 6, 101519. **DOI:**10.1016/j.jksus.2021.101519

[14] Johnson W Jr, Bergfeld WF, Belsito DV, Hill RA, Klaassen CD, Liebler DC, Marks JG Jr, Shank RC, Slaga TJ, Snyder PW, Gill LJ, Heldreth B; (2020) Safety Assessment of Silk Protein Ingredients as Used in Cosmetics. Int J Toxicol 39(3_suppl), 127S–144S. **DOI:**10.1177/1091581820966953
[15] Gavazzoni Dias MF; (2015) Hair cosmetics: an overview. Int J Trichology 7(1), 2–15. **DOI:**10.4103/0974–7753.153450
[16] Łętocha A, Miastkowska M, Sikora E; (2022) Preparation and Characteristics of Alginate Microparticles for Food, Pharmaceutical and Cosmetic Applications. Polymers 14, 3834. **DOI:**10.3390/polym14183834
[17] Petri DFS; (2015) Xanthan gum: a versatile biopolymer for biomedical and technological applications. J Appl Polym Sci 132, 42035. **DOI:**10.1002/app.42035
[18] Olivato JB; (2024), Starch: a natural, safe, and multifunctional ingredient for cosmetic formulations. In: Pascoli Cereda M, Francois Vilpoux O (eds), Starch Industries: Processes and Innovative Products in Food and Non-Food Uses. Academic Press, 255–269. **DOI:**10.1016/B978-0-323-90842-9.00007-8
[19] Ratajczak P, Maciejak O, Kopciuch D, Paczkowska A, Zaprutko T, Kus K; (2023) Directions of hyaluronic acid application in cosmetology. J Cosmet Dermatol 22(3), 862–871. **DOI:**10.1111/jocd.15485
[20] Juncan AM, Moisă DG, Santini A, Morgovan C, Rus LL, Vonica-Țincu AL, Loghin F; (2021) Advantages of Hyaluronic Acid and Its Combination with Other Bioactive Ingredients in Cosmeceuticals. Molecules 26(15), 4429. **DOI:**10.3390/molecules26154429
[21] Bianchet RT, Vieira Cubas AL, Machado MM, Siegel Moecke EH; (2020) Applicability of bacterial cellulose in cosmetics – bibliometric review. Biotechnol Rep 27, e00502. **DOI:**10.1016/j.btre.2020.e00502
[22] Shafie MH, Kamal ML, Zulkiflee FF, Hasan S, Uyup NH, Abdullah S, Hussin NAM, Tan YC, Zafarina Z; (2022) Application of carrageenan extract from red seaweed (Rhodophyta) in cosmetic products: a review. J Indian Chem Soc 99(9), 100613. **DOI:**10.1016/j.jics.2022.100613
[23] Roman-Benn A, Contador CA, Li MW, Lam HM, Ah-Hen K, Ulloa PE, Ravanal MC; (2023) Pectin: an overview of sources, extraction and applications in food products, biomedical, pharmaceutical and environmental issues. Food Chem Adv 2, 100192. **DOI:**10.1016/j.focha.2023.100192
[24] Piekarska K, Sikora M, Owczarek M, Jóźwik-Pruska J, Wiśniewska-Wrona M; (2023) Chitin and Chitosan as Polymers of the Future-Obtaining, Modification, Life Cycle Assessment and Main Directions of Application. Polymers 15, 793. **DOI:**10.3390/polym15040793
[25] Anchisi C, Meloni MC, Maccioni AM; (2007) Chitosan beads loaded with essential oils in cosmetic formulations. Int J Cosmetic Sci 29, 485–485. **DOI:**10.1111/j.1468-2494.2007.00371_1.x
[26] Pires PC, Mascarenhas-Melo F, Pedrosa K, Lopes D, Lopes J, Macário-Soares A, Peixoto D, Giram PS, Veiga F, Paiva-Santos AC; (2023) Polymer-based biomaterials for pharmaceutical and biomedical applications: A focus on topical drug administration. Eur Polym J 187, 111868. **DOI:**10.1016/j.eurpolymj.2023.111868
[27] Gawade RP, Chinke SL, Alegaonkar PS; (2020) Polymers in cosmetics. In: AlMaadeed MAA, Ponnamma D, Carignano MA (eds), Polymer Science and Innovative Applications. Elsevier, 545–565. **DOI:**10.1016/B978-0-12-816808-0.00017-2
[28] Maia Campos PMBG, de Melo MO, de Camargo Junior FB; (2014) Effects of Polysaccharide-Based Formulations on Human Skin. In: Ramawat K, Mérillon JM (eds), Polysaccharides. Springer, Cham. **DOI:**10.1007/978-3-319-03751-6_64-1

[29] Pellis A, Guebitz GM, Nyanhongo GS; (2022) Chitosan: Sources, Processing and Modification Techniques. Gels 8(7), 393. **DOI:**10.3390/gels8070393

[30] Younes I, Rinaudo M; (2015) Chitin and chitosan preparation from marine sources. Structure, properties and applications. Mar Drugs 13(3), 1133–74. **DOI:**10.3390/md13031133

[31] Chen Q, Qi Y, Jiang Y, Quan W, Luo H, Wu K, Li S, Ouyang Q; (2022) Progress in Research of Chitosan Chemical Modification Technologies and Their Applications. Mar Drugs 20(8), 536. **DOI:**10.3390/md20080536

[32] Bastiaens L, Soetemans L, D'Hondt E, Elst K; (2019) Sources of Chitin and Chitosan and their Isolation. In: van den Broek LAM, Boeriu CG (eds), Chitin and Chitosan: Properties and Applications. John Wiley & Sons Ltd., 1–34. **DOI:**10.1002/9781119450467.ch1

[33] Vokhidova NR, Ergashev KH, Rashidova SS; (2022) Synthesis and application of chitosan hydroxyapatite: a review. Prog Chem Appl Chitin Deriv 27, 5–34. **DOI:**10.15259/PCACD.27.001

[34] Petroni S, Tagliaro I, Antonini C, D'Arienzo M, Orsini SF, Mano JF, Brancato V, Borges J, Cipolla L; (2023) Chitosan-Based Biomaterials: Insights into Chemistry, Properties, Devices, and Their Biomedical Applications. Mar Drugs 21, 147. **DOI:**10.3390/md21030147

[35] Aranda-Barradas ME, Trejo-López SE, Real AD, Álvarez-Almanazán S, Méndez-Albores A, García-Tovar CG, Conzález-Díaz FR, Miranda-Castro SP; (2022) Effect of molecular weight of chitosan on the physicochemical, morphological, and biological properties of polyplex nanoparticles intended for gene delivery. Carbohydr Polym Technol Appl 4, 100228. **DOI:**10.1016/j.carpta.2022.100228

[36] Piegat A, Goszczyńska A, Idzik T, Niemczyk A; (2019) The Importance of Reaction Conditions on the Chemical Structure of N,O-Acylated Chitosan Derivatives. Molecules 24, 3047. **DOI:**10.3390/molecules24173047

[37] Sorlier P, Denuzière A, Viton C, Domard A; (2001) Relation between the Degree of Acetylation and the Electrostatic Properties of Chitin and Chitosan. Biomacromol 2, 765–72. **DOI:**10.1021/bm015531+

[38] Aranaz I, Alcántara AR, Civera MC, Arias C, Elorza B, Heras Caballero A, Acosta N; (2021) Chitosan: an overview of its properties and applications. Polymers 13, 3256. **DOI:**10.3390/polym13193256

[39] Roy J, Salaün F, Giraud S, Ferri A, Guan J, Chen G; (2017) Solubility of Chitin: Solvents, Solution Behaviors and Their Related Mechanisms. **DOI:**10.5772/intechopen.71385

[40] Ahmadi F, Oveisi Z, Samani SM, Amoozgar Z; (2015) Chitosan based hydrogels: Characteristics and pharmaceutical applications. Res Pharma Sci 10, 1–16.

[41] Cai Z, Chen P, Jin H-J, Kim J; (2009) The effect of chitosan content on the crystallinity, thermal stability, and mechanical properties of bacterial cellulose-chitosan composites. J Mech Eng Sci 223, 2225–2230. **DOI:**10.1243/09544062JMES1480

[42] Wu Q-X, Lin D-Q, Yao S-J; (2014) Design of Chitosan and Its Water Soluble Dericatives-Based Drug Carriers with Polyelectrolyte Complexes. Mar Drugs 12, 6236–6253. **DOI:**10.3390/md12126236

[43] Wadhwa S, Paliwal R, Paliwal SR, Vyas SP; (2009) Chitosan and its Role in Ocular Therapeutic. Mini Rev Med Chem 9, 1639–1647. **DOI:**10.2174/138955709791012292

[44] Victor RS, Santos ADM, Sousa BV, Neves GA, Santana LNL, Menezes RR; (2020) A Review on Chitosan's Uses as Biomatrial: Tissue Engineering, Drug Delivery Systems and Cancer Treatment. Materials 13, 4995. **DOI:**10.3390/ma13214995

[45] Zaharoff DA, Rogers CJ, Hance KW, Schlom J, Greiner JW; (2007) Chitosan solution enhances both humoral and cell-mediated immune responses to subcutaneous vaccination. Vaccine 25(11), 2085–94. **DOI:**10.1016/j.vaccine.2006.11.034

[46] Fan P, Zeng Y, Zaldivar-Siva D, Agüero L, Wang S; (2023) Chitosan-Based Hemostatic Hydrogels: The Concept, Mechanism, Application, and Prospects. Molecules 28(3), 1473. **DOI:**10.3390/molecules28031473

[47] Upadhyay U, Sreedhar I, Singh SA, Patel CM, Anitha KL; (2021) Recent advances in heavy metal removal by chitosan based adsorbents. Carbohydr Polym 251, 117000. **DOI:**10.1016/j.carbpol.2020.117000

[48] Maher ZE, Entsar SA; (2013) Chitosan based edible films and coatings: a review. Mater Sci Eng C 33(4), 1819–1841. **DOI:**10.1016/j.msec.2013.01.010

[49] Rodrigues S, Dionísio M, López CR, Grenha A; (2012) Biocompatibility of Chitosan Carriers with Application in Drug Delivery. J Funct Biomater 3, 615–641. **DOI:**10.3390/jfb3030615

[50] Ke C, Deng F, Chuang C, Lin C; (2021) Antimicrobial Actions and Applications od Chitosan. Polymers 13, 904. **DOI:**10.3390/polym13060904

[51] Ngo DH, Kim SK; (2014) Antioxidant effects of chitin, chitosan and their derivatives. Adv Food Nutr Res 73, 15–31. **DOI:**10.1016/B978-0-12-800268-1.00002-0

[52] Ways TMM, Lau WM, Khutoryanskiy VV; (2018) Chitosan and Its Derivatives for Application in Mucoadhesive Drug Delivery Systems. Polymers 10, 267. **DOI:**10.3390/polym10030267

[53] Tzeng H-P, Liu S-H, Chiang M-T; (2022) Antidiabetic Properties of Chitosan and Its Derivatives. Mar Drugs 20, 784. **DOI:**10.3390/md20120784

[54] Sikorski D, Bauer M, Frączyk J, Draczyński Z; (2022) Antibacterial and Antifungal Properties of Modified Chiosan Nonwovens. Polymers 14, 1690. **DOI:**10.3390/polym14091690

[55] Zhang J, Tan W, Luan F, Yin X, Dong F, Li Q, Guo Z; (2018) Synthesis of Quaternary Ammonium Salts of Chitosan Bearing Halogenated Acetate for Antifungal and Antibacterial Activities. Polymers 10, 530. **DOI:**10.3390/polym10050530

[56] Jonson NR, Wang Y; (2015) Drug Delivery Systems for Wound Healing. Curr Pharm Biotechnol 16(7), 621–629. **DOI:**10.2174/1389201016666150206113720

[57] Tatara AM, Kontoyiannis DP, Mikos AG; (2018) Drug delivery and tissue engineering to promote wound healing in the immunocompromised host: current challenges and future directions. Adv Drug Deliv Rev 129, 319–329. **DOI:**10.1016/j.addr.2017.12.001

[58] Yayehrad AT, Siraj EA, Matsabisa M, Birhanu G; (2023) 3D printed drug loaded nanomaterials for wound healing applications. Regen Ther 24, 361–376. **DOI:**10.1016/j.reth.2023.08.007

[59] Saghazadeh S, Rinoldi C, Schot M, Kashaf SS, Sharifi F, Jalilian E, Nuutila K, Giatsidis G, Mostafalu P, Derakhshandeh H, Yue K, Swieszkowski W, Memic A, Tamayol A, Khademhosseini A; (2018) Drug delivery systems and materials for wound healing applications. Adv Drug Deliv Rev 127, 138–166. **DOI:**10.1016/j.addr.2018.04.008

[60] Abedian Z, Moghadamnia A, Zabihi E, Pourbagher R, Ghasemi M, Nouri HR, Tashakorian H, Jenabian N; (2019) Anticancer properties of chitosan against osteosarcoma, breast cancer and cervical cancer cell lines. Casp J Intern Med 10, 439–446. **DOI:**10.22088/cjim.10.4.439

[61] Friedman AJ, Phan J, Schairer DO, Champer J, Qin M, Pirous A, Blecher-Paz K, Oren A, Liu PT, Modlin RL, Kim J; (2012) Antimicrobial and anti-inflammatory activity of chitosan-alginate nanoparticles: a targeted therapy for cutaneous pathogens. J Invest Dermatol 133(5), 1231–1239. **DOI:**10.1038/jid.2012.399

[62] Thanou M, Verhoef JC, Junginger HE; (2001) Chitosan and its derivatives as intestinal absorption enhancers. Adv Drug Deliv Rev 50, 91–101. **DOI:**10.1016/s0169-409x(01)00180-6
[63] Lewandowska K, Szulc M; (2022) Rheological and Film-Forming Properties of Chitosan Composites. Int J Mol Sci 23, 8763. **DOI:**10.3390/ijms23158763
[64] Zhang W, Cao J, Jiang W; (2022) Analysis of film-forming properties of chitosan with different molecular weights and its adhesion properties with different postharvest fruit surfaces. Food Chem 395, 133605. **DOI:**10.1016/j.foodchem.2022.133605
[65] Verma C, Quraishi MA; (2021) Chelation capability of chitosan and chitosan derivatives: Recent developments in sustainable corrosion inhibition and metal decontamination applications. Curr Res Green Sustain Chem 4, 100184. **DOI:**10.1016/j.crgsc.2021.100184
[66] Herdiana Y, Wathoni N, Shamsuddin S, Muchtaridi M; (2021) Drug release study of the chitosan-based nanoparticles. Heliyon 8(1), e08674. **DOI:**10.1016/j.heliyon.2021.e08674
[67] Safdar R, Omar AA, Arunagiri A, Regupathi I, Thanabalan M; (2019) Potential of chitosan and its derivatives for controlled drug release application – a review. J Drug Deliv Sci Technol 49, 642–659. **DOI:**10.1016/j.jddst.2018.10.020
[68] Prabaharan M, Mano JF; (2004) Chitosan-Based Particles as Controlled Drug Delivery System. Drug Deliv 12, 41–57. **DOI:**10.1080/10717540590889781
[69] Farasati Far B, Omrani M, Naimi-Jamal MR, Javanshir S; (2023) Multi-responsive chitosan-based hydrogels for controlled release of vincristine. Commun Chem 6, 28(2023). **DOI:**10.1038/s42004-023-00829-1
[70] Maksym PV, Sikora V; (2015) Chitosan as a Hemostatic Agent: Current State. Eur J Med Ser B 2, 24–33. **DOI:**10.13187/ejm.s.b.2015.2.24
[71] Liu Z, Xu Y, Su H, Jing X, Wang D, Li S, Chen Y, Guan H, Meng L; (2023) Chitosan-based hemostatic sponges as new generation hemostatic materials for uncontrolled bleeding emergency: modification, composition, and application. Carbohydr Polym 311, 120780. **DOI:**10.1016/j.carbpol.2023.120780
[72] Fong D, Hoemann CD; (2017) Chitosan immunomodulatory properties: perspectives on the impact of structural properties and dosage. Future Sci OA 4(1), FSO225. **DOI:**10.4155/fsoa-2017-0064
[73] Mohamad N, Nadiah AHN, Jeefferie AR, Fairuz DM; (2013) Effect of Chitosan Gelatinization Temperature on Water Absorption and Water Retention of Chitosan-Based Urea Fertilizer. Int J Automot Mech Eng 8, 1357–1366. **DOI:**10.15282/ijame.8.2013.23.0111
[74] [Trinh TH, KuShaari K; (2016) Dynamic of Water Absorption in Controlled Release Fertilizer and its Relationship with the Release of Nutrient. Procedia Eng 148, 319–326. **DOI:**10.1016/j.proeng.2016.06.444
[75] Sreerag G, Sabu T, Anitha P; (2020) Chitin and Chitosan based Polymer Materials for Various Applications. In: Sreerag G, Sabu T, Anitha P (eds), Handbook of Chitin and Chitosan. Vol. 3. Elsevier, 71–88. **DOI:**10.1016/C2018-0-02998-9
[76] Guzmán E, Ortega F, Rubio RG; (2022) Chitosan: A Promising Multifunctional Cosmetic Ingredient for Skin and Hair Care. Cosmetics 9, 99. **DOI:**10.3390/cosmetics9050099
[77] Kulka K, Sionkowska A; (2023) Chitosan based materials in cosmetic applications: a review. Molecules 28, 1817. **DOI:**10.3390/molecules28041817
[78] Ju S, Shin G, Lee M, Koo JM, Jeon H, Ok YS, Hwang DS, Kwang SY, Oh DX, Park J; (2021) Biodegradable chito-beads replacing non-biodegradable microplastics for cosmetics. Green Chem 23, 6953–6965. **DOI:**10.1039/D1GC01588E

[79] Zhang X, Li Y, Guo M, Jin TZ, Arabi SA, He Q, Ismail BB, Hu Y, Liu D; (2021) Antimicrobial and UV Blocking Properties of Composite Chitosan Films with Curcumin Grafted Cellulose Nanofiber. Food Hydrocoll 112, 106337. **DOI:**10.1016/j.foodhyd.2020.106337

[80] Aranaz I, Acosta N, Civera C, Elorza B, Mingo J, Castro C, Gandía ML, Caballero AH; (2018) Cosmetics and Cosmeceutical Applications of Chitin, Chitosan and Their Derivatives. Polymers 10, 213. **DOI:**10.3390/polym10020213

[81] EWG's Skin Deep®. Your Guide to Safer Personal Care Products. Available online: EWG Skin Deep® Cosmetics Database

[82] Firmansyah E, Hardiyanti R, Samosir AK, Sitepu MPB, Siagian NB; (2022) Preparation and Characterization of Chitosan from Golden Scales for Ani-dandruff Shampoo. Rasayan J Chem 15(2), 1340–1344. **DOI:**10.31788/RJC.2022.1526755

[83] Luo C, Zhou L, Chiou K, Huang J; (2018) Multifunctional Graphene Hair Dye. Chem 4, 784–794. **DOI:**10.1016/j.chempr.2018.02.021

[84] Abd El-Hack ME, El-Saadony MT, Shafi ME, Zabermawi NM, Arif M, Batiha GE, Khafaga AF, Abd El-Hakim YM, Al-Sagheer AA; (2020) Antimicrobial and antioxidant properties of chitosan and its derivatives and their applications: a review. Int J Biol Macromol 164, 2726–2744. **DOI:**10.1016/j.ijbiomac.2020.08.153

[85] Thambiliyagodage C, Jayanetti M, Mendis A, Ekanayake G, Liyanaarachchi H, Vigneswaran S; (2023) Recent advances in chitosan-based applications – a review. Materials 16(5), 2073. **DOI:**10.3390/ma16052073

[86] Casadidio C, Peregrina DV, Gigliobianco MR, Deng S, Censi R, Di Martino P; (2019) Chitin and chitosans: characteristics, eco-friendly processes, and applications in cosmetic science. Mar Drugs 17(6), 369. **DOI:**10.3390/md17060369

[87] Latheef F, Wilkinson M; (2020) Adverse skin reactions to cosmetics and skin care products. In: Johansen JD, Mahler V, Lepoittevin JP, Frosch PJ (eds), Contact Dermatitis. Springer, New York, 913–932. **DOI:**10.1007/978-3-030-36335-2_83

[88] Cristiano L, Guagni M; (2022) Zooceuticals and Cosmetic Ingredients Derived from Animals. Cosmetics 9, 13. **DOI:**10.3390/cosmetics9010013

[89] Yadav M, Kaushik B, Rao GK, Srivastava CM, Vaya D; (2023) Advances and challenges in the use of chitosan and its derivatives in biomedical fields: a review. Carbohydr Polym Technol Appl 5, 100323, **DOI:**10.1016/j.carpta.2023.100323

[90] WO/2017/177027– Hydrophobically-modified chitosan for use in cosmetics and personal care applications (patent, publication date: 12.10.2017)

[91] Kodolova-Chukhontseva VV, Dresvyanina EN, Nashchekina YA, Dobrovol'skaya IP, Bystrov SG, Ivan'kova EM, Yudin VE, Morganti P; (2022) Application of the Composite Fibers Based on Chitosan and Chitin Nanofibrils in Cosmetology. J Funct Biomater 13(4), 198. **DOI:**10.3390/jfb13040198

[92] Kodolova-Chukhontseva VV, Rozova EY, Dresvyanina EN, Nashchekina YA, Dobrovol'skaya IP, Vlasova EN, Bystrov SG, Popova EN, Maslennikova TP, Yudin VE, Morganti P; (2023) New Composite Materials Based on Chitosan Films Reinforced with Chitin Nanofibrils for Cosmetic Application. Cosmetics 10, 51. **DOI:**10.3390/cosmetics10020051

[93] Ta Q, Ting J, Harwood S, Browning N, Simm A, Ross K, Olier I, Al-Kassas R; (2021) Chitosan nanoparticles for enhancing drugs and cosmetic components penetration through the skin. Eur J Pharm Sci 160, 105765. **DOI:**10.1016/j.ejps.2021.105765

[94] Sahudin S, Sahrum Ayumi N, Kaharudin N; (2022) Enhancement of Skin Permeation and Penetration of β-Arbutin Fabricated in Chitosan Nanoparticles as the Delivery System. Cosmetics 9, 114. **DOI:**10.3390/cosmetics9060114