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Review Article

Nanoparticles and Nanoliposomes for Hair Growth Serum

Nanopartikel dan Nanoliposom untuk Serum Pertumbuhan Rambut

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Abstract

Solubility in penetrating the follicles is the main obstacle in the formulation of hair growth serum preparation with chemicals derived from natural or synthetic materials. Therefore, a delivery system is needed to deliver more chemical compounds into the follicles. Nanoparticles and nanoliposomes are potential chemical compound delivery systems in hair growth serum. Specifically, nanoparticles with a particle size of less than 200 nm can increase the transport of serum chemical compounds into the scalp. The small particle size makes the interaction between atoms and molecules faster and prevents clumping with the repulsive force of dispersed particles. Meanwhile, nanoliposomes with lipids as encapsulation in the delivery of lipophilic or hydrophilic chemical compounds with nanosizes can significantly increase serum diffusion on the scalp.

Keywords: chemical aggregation; dispersion; nanoliposomes, nanoparticles; serum

Abstrak

Kendala utama formulasi serum dari bahan alam maupun sintesis yang dapat menembus folikel adalah kelarutan. Sistem penghantaran diperlukan untuk menghantarkan senyawa kimia lebih banyak masuk ke dalam folikel. Nanopartikel dan nanoliposom adalah sistem penghantaran senyawa kimia potensial pada serum penumbuh rambut. Sediaan nanopartikel memiliki ukuran partikel kurang dari 200 nm akan meningkatkan transport senyawa kimia serum masuk ke dalam kulit kepala. Ukuran partikel yang kecil menjadikan interaksi antar atom dan molekulnya semakin cepat dan dapat menjaga dari agregasi partikel dengan gaya tolak menolak dari partikel terdispersi sehingga dapat menstabilkan diri. Sediaan nanoliposom yang menjadikan lipid sebagai enkapsulasi pada penghantaran senyawa kimia yang bersifat lipofilik maupun hidrofilik dengan ukuran nano dapat meningkatkan secara signifikan difusi serum pada kulit kepala.

***Kata kunci**: agregasi senyawa kimia; dispersi; nanoliposom; nanopartikel; serum*

1. Introduction

The hair growth serum is a cosmetic formulation with great potential [1]. It is formulated with active substances derived from natural ingredients and has advantages such as minimal side effects, abundant availability, and easy extraction [2]. In serum preparations, solubility in penetrating the scalp is usually the main obstacle [3]. Solubility can be increased with the right formulation to deliver more active substances into the follicles and achieve optimal therapeutic effects [4]. To overcome low solubility, serum preparations should be developed into nanoparticles and nanoliposomes [5–7].

Nanoparticles in serum preparations are made with particle sizes below 200 nm [8] using nanotechnology. Several studies showed that nanoparticles have been successfully developed in cosmetic preparations. Pulit-Prociak et al., stated that nanoparticle preparations are safe to use in cosmetics containing nanosilver and nanogold [9]. ZnO particles measuring 1 to 100 µm can be synthesized by adding a capping agent, a compound that plays a role in preventing clumping to avoid colloid destabilization.

Nanoparticles have been successfully formulated into moisturizing creams [10]. Lee et al., formulated a hair growth nanoparticle serum from *Phellinus linteus*, *Cordyceps militaris*, *Polygonum multiflorum*, *Ficus carica*, and *Cocos nucifera oils* containing 4HGF. Poly-γ-glutamic acid (γ-PGA) combined with 4HGF has semipolar properties, interacting with a slow-release system of target ligands and thereby dispersing more substances [11]. Aside from nanoparticles, to improve the delivery system of active substances, serum can also be formulated into nanoliposomes.

Nanoliposomes are the latest technology for the controlled release of bioactive compounds and increasing the stability of the preparations. The application helps increase the delivery of active substances through lipid membranes to enter skin cells. Several publications mentioned that nanoliposomes have been used for cosmetic preparations. Hydroxylated collagen has nonpolar properties, and is insoluble in water, hence, it is difficult to diffuse into the skin, which is semipolar. To increase dispersion into the skin, hydroxylated collagen is synthesized semipolarly with a liposome system [12]. According to Amnuaikit et al., the formulation of hydroxylated collagen in the form of liposomes in serum form can help increase skin penetration, remove unwanted odors, and mask colors by the appropriate lipid bilayer structure. Hameed et al., explained that sunscreens with inorganic materials such as TiO_2 and ZnO_2 metals are better in nanoliposome preparations. TiO_2 and ZnO_2 have thin layer absorption, are nonpolar, insoluble in water, and serve as catalysts. The development of particles to nanosize, and coating with semipolar substances will increase absorption on the skin [13].

This review discusses the potential of nanoparticles and nanoliposomes in hair growth serum preparations. Nanoparticles and nanoliposomes can significantly increase the penetration of active substances contained in serum into the skin, thereby increasing the therapeutic effect. The development of both technologies will have a major impact on the process of delivering active substances to the target.

2. Research Methods

This review was based on literature studies from Google Scholar, Pubmed, and Scopus. The keywords used were nanoparticles, nanoliposomes, serum, solubility, and compound aggregation. A total of 48 studies that discussed nanoparticles or nanoliposomes were retrieved.

3. Serum Preparation

Serum is a cosmetic product that contains active ingredients with high concentrations to provide intensive nutrition to the skin layer. The nature of the active ingredients can be polar, nonpolar, or semipolar. The difference in the chemical properties will provide a difference in the speed of diffusion into the skin which is semipolar. Polar and nonpolar compounds are more difficult to diffuse into the skin. This is due to the difference in electronegativity between the atoms in the active substance of the serum and the skin barrier [14].

Preparations are widely used in the cosmetic industry, one of which is hair growth serum. Specifically, serum preparations are classified as emulsions that have low viscosity [15]. This nature increases the pressure and speed at which the particles rub against each other, leading to rapid delivery of active substances to the skin surface [16]. Another advantage of serum preparations is the high concentration of active substances. This aims to increase the desired therapeutic effect [17, 18].

The formulation of serum preparations used for hair growth should meet several parameters, including organoleptic, adhesive, and spreading power, as well as pH and viscosity [19]. The organoleptic properties of serum must meet the parameters of clarity and softness [20]. The adhesive power that meets the standards must not exceed four seconds. The spreading power does not have a definite value but is considered acceptable between 5-8 [21]. The pH value that enters the skin preparation is 5.5-7.4, while the viscosity is in the range of 2000-4000 cps [22]. Serum preparations that do not meet all of these parameters have the risk of being uncomfortable to use or achieve therapeutic targets.

Several publications stated that effective serum preparations for hair growth are those derived from natural extracts. According to Nabilla et al., apple juice formulated in serum preparations has been shown to increase hair growth in mice. Apple extract contains procyanidin B-2, which binds to metal and becomes a catalyst to accelerate hair follicle growth [23]. According to Collins et al., the combination of candlenut oil and apple extract is also effective in increasing hair growth. Oleic acid in candlenut oil extracted using semipolar solvents can increase diffusion in the skin [24]. In serum preparations, one major obstacle is the solubility of active substances to diffuse into the skin. This obstacle can be overcome by changing serum into nanoparticles and nanoliposomes [25, 26].

4. Nanoparticles

Nanoparticles are colloidal particles that can deliver chemical compounds specifically. Various nanotechnology-based systems include polymer and magnetic nanoparticles, carbon nanotubes, quantum dots, dendrimers, metal nanoparticles, and liposomes [27]. Each type has different advantages. Polymer nanoparticles have advantages due to the ability to effectively standardize particle size. The target of

polymer nanoparticles is the delivery of chemicals to cells [28]. Meanwhile, magnetic nanoparticles can be used as strong carriers and magnetic hyperthermia agents in response to external magnetic fields. Another advantage is that magnetic nanoparticles can act as resonance imaging agents, which allow precise detection of the target location in chemical delivery [29]. Carbon nanotube nanoparticles function in detecting and distinguishing various analytes based on the chemical properties of the substance [30].

The advantages of quantum dot nanoparticles are immunohistochemical analysis, single molecule tracking, and in vivo imaging compared to traditional methods with organic dyes and fluorescent proteins. The unique spectral properties of these nanoparticles offer the opportunity to design systems for multiplex analysis with multicolor imaging to detect multiple targets simultaneously. Conjugation of chemical molecules to quantum dot nanoparticle-based delivery particles allows for real-time monitoring of chemical tracking [31].

Dendrimer nanoparticles can transport large amounts of chemicals to a specific area [32]. Furthermore, metal nanoparticles have the advantage of increasing the delivery of active substances [33]. Liposomes are one type of nanoparticle that functions as a carrier to release controlled and targeted chemicals without degradation [34]. The systematics of nanoparticles in the active substance delivery system are presented in Figure 1.

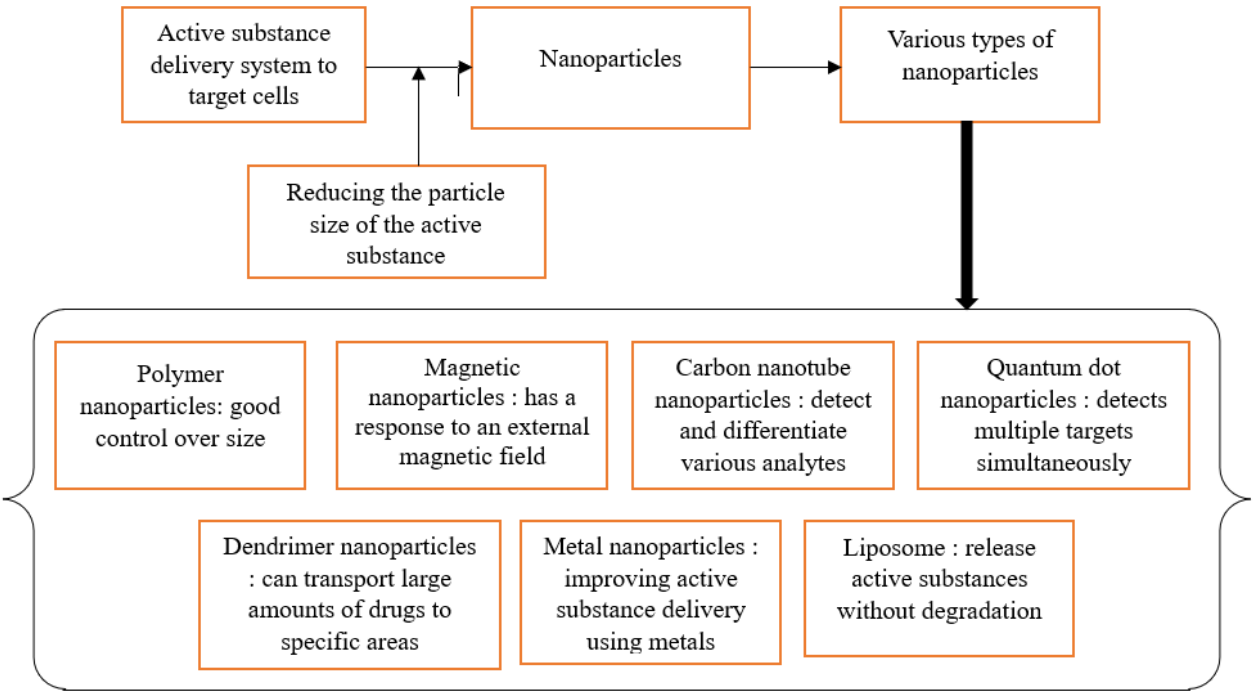

Figure 1. Systematization of Nanoparticle Types in Active Substance Delivery System

5. Nanoliposomes

Nanoliposomes refer to small-sized liposomes and are one of the most frequently examined colloidal delivery systems in food, nutraceutical, drug, and cosmetic studies. This is attributed to the significant capacity to deliver bioactive substances hydrophilically and hydrophobically. Nanoliposomes have been used in several studies and industrial products [35]. The advantages include protecting sensitive chemical compound molecules, stable storage, high loading capacity, increased bioavailability, and sustained release mechanisms. Furthermore, nanoliposomes can deliver lipophilic and hydrophilic materials simultaneously, providing a synergistic effect. Chemical compounds soluble in water and fat can be dispersed into one due to the coating by a lipid barrier [36]. Nanoliposomes are widely formulated for cosmetic preparations.

Several publications mentioned that the use of nanoliposomes for cosmetics can increase the bioavailability of active substances. According to Kocid et al., nanoliposomes successfully increased the levels of active substances in skin care serum derived from soy milk [37]. Saewan et al. added that nanoliposomes increased in vitro and in vivo tests of anti-aging serum from coffee beans [38]. These materials have also been shown to increase the solubility of active substances when applied to serum preparations.

6. Nanoparticles for Hair Growth Serum Preparation

Hair growth serums are widely formulated with nanoparticles technology to achieve the desired target. Several publications on nanoparticles for serum preparations are presented in Table 1.

Table 1. Nanoparticle application for hair growth serum

No	Author	Results	Reference
1	Costa et al., 2021	Three common types of nanoparticles were compared in terms of viability and durability, for example, liposomes, ethosomes, and polymer nanoparticles. Serum enumeration was able to supply, both stable models to more significant follicular areas than nanoparticles.	[39]
2	Tansathien et al., 2021	Niosome serum mucrospicules containing deer antler velvet removal played a basic portion in communicating biomacromolecular protein through the skin and hair follicles, driving practical hair improvement	[40]
3	Takabayashi et al., 2016	The pitiless breadth of the hairs was basically higher after the application of FGF-2&D/P NPs for six months. Objective headways in incline hair were observed in two cases. Nine individuals experienced more significant bounce and hair adaptability	[41]
4	Fernandes et al., 2015	The optimized procedure licenses the course of action of culminating PLA nanoparticles-based points of interest for hair follicle centering. PLA nanoparticles can suitably transport and release lipophilic and hydrophilic compounds into the hair follicles, and the yields obtained are commendable for mechanical purposes.	[42]
5	Kong et al,. 2022	The optimized technique grants the course of action of culminating PLA nanoparticles-based points of interest for hair follicle centering. PLA nanoparticles can reasonably transport and release lipophilic and hydrophilic compounds into the hair follicles, and the yields obtained are commendable for mechanical purposes.	[43]

Table 1 shows that nanoparticles can effectively increase hair growth to overcome alopecia. Through various mechanisms, nanoparticles effectively increase the active serum substances in the follicles, facilitating hair growth. The particle size of the chemical compound is very small and can penetrate the spaces between cells. The ability of nanoparticles to penetrate cell walls is high, both through diffusion and opsonification, as well as the flexibility to be combined. Therefore, nanoparticles are a viable option in the chemical delivery system. The very small particle size enhances rapid delivery of active substances into the follicles through the diffusion system. This preparation does not require significant energy to increase the desired effect.

7. Nanoliposomes for Hair Growth Serum Preparation

Nanoliposomes are nanosized particles coated with a lipid membrane to enhance the transport of more chemicals into the hair follicles. Some publications on nanoliposomes for hair growth serum are presented in Table 2.

Table 2. Nanoliposome application for hair growth serum

No	Author	Results	Reference
1	Tian et al., 2022	Nanoliposomes were stacked with copper peptide, acetyl tetrapeptide-3, and myristoyl pentapeptide-4 (CAM-NLPs) at the same time to achieve a synergistic effect of various bioactive peptides combination for transport efficiency in progressing hair improvement. In rundown, CAM-NLPs are compelling transdermal co-delivery nanocarriers for lessening hair incidents in androgenetic alopecia with hair advancement progression, tall security, and uncommon potential	[44]
2	Zhang et al., 2024	Energized by nanoliposomes and MNs, the exemplified KK-NLPs performed capable skin penetration and moved forward cellular internalization into human dermal papilla cells. Exceptionally, the KK-NLPs-integrated MNs treatment bunch appears basic progressed hair recuperation in vivo, with unclear or predominant accommodating impacts at a much lower estimation than that of minoxidil.	[45]
3	Xu et al., 2018	FGF-2-LIP-SF may be a potential option to prevent hair loss in patients with alopecia areata.	[46]
4	Tanrivedi et al., 2022	Pomegranate peel extract-loaded liposomes were sketched out for hair color security. Organized definitions have an awesome color affirmation on hair strands due to the antioxidant properties of pomegranate peel removal and the film-forming effect of liposomal definitions. Organized liposomal definitions may serve as an incredible elective for lessening coloring repeat and securing hair fibers.	[47]
5	Liu et al., 2024	The nanopreparations had no self-evident skin bothering. The CAR-loaded liposomal definition has potential application for the treatment of AGA.	[48]

Table 2 shows that nanoliposomes can be used to overcome hair loss through serum preparations. Nanoliposomes are effective in delivering chemicals from natural and synthetic materials into hair serum. Furthermore, nanoparticles and nanoliposomes in serum preparations can increase the penetration of chemicals into hair follicles, making both effective for alopecia therapy. The spherical shape of nanoliposomes also makes this preparation easier to diffuse through the intercellular barrier membrane. Chemicals with different levels of polarity when encapsulated in nanoliposomes will have greater solubility. The potential of nanoparticles and nanoliposomes for hair growth serum is presented in Figure 2.

8. Conclusion

In conclusion, nanoparticles and nanoliposomes have great potential to be developed in hair growth serum preparations. Nanoparticles have particle sizes of less than 200 nm which increase the transport of serum chemicals into the scalp. Furthermore, the small particle size makes the interaction between atoms and molecules faster and can prevent clumping with the repulsive force of dispersed particles. Nanoliposomes with lipids as encapsulation in the delivery of nano-sized chemicals can significantly increase serum diffusion on the scalp.

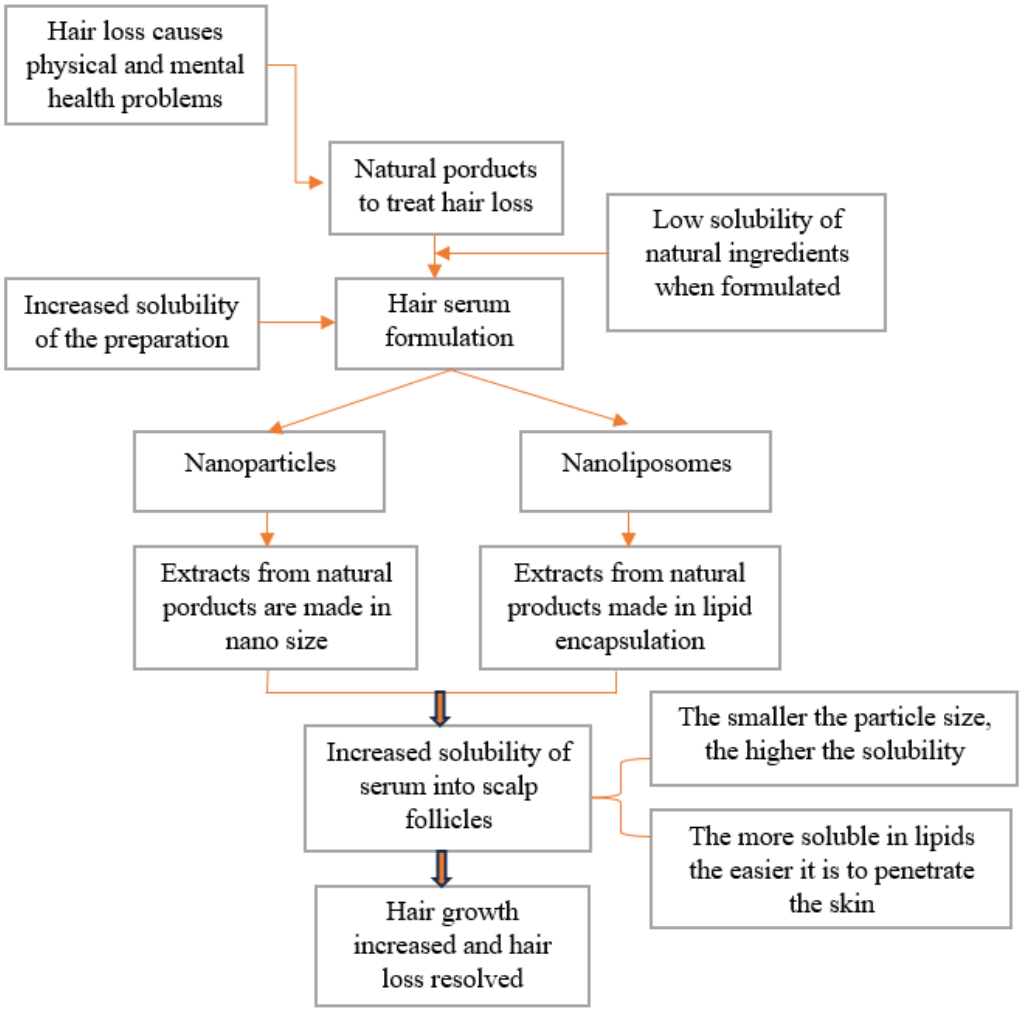

Figure 2. The potential of nanoparticle and nanoliposome preparations for a hair growth serum

References

[1] Majeed, M., Majeed, S., Nagabhushanam, K., Mundkur, L., Neupane, P., & Shah, K. (2020). Clinical study to evaluate the efficacy and safety of a hair serum product in healthy adult male and female volunteers with hair fall. *Clinical, Cosmetic and Investigational Dermatology*, 13, 691–700. doi: 10.2147/CCID.S271013

[2] Bubalo, M. C., Vidović, S., Redovniković, I. R., & Jokić, S. (2018). New perspective in extraction of plant biologically active compounds by green solvents. *Food and Bioproducts Processing*, 109, 52–73. doi: 10.1016/J.FBP.2018.03.001

[3] Vaishampayan, P., & Rane, M. M. (2022). Herbal Nanocosmecuticals: A Review On Cosmeceutical Innovation. *Journal of Cosmetic Dermatology*, 21(11), 5464–5483. doi: 10.1111/JOCD.15238

[4] Patzelt, A., & Lademann, J. (2020). Recent advances in follicular drug delivery of nanoparticles. *Expert Opinion on Drug Delivery*, 17(1), 49–60. doi: 10.1080/17425247.2020.1700226

[5] Alishiri, M., Ebrahimi, S., Shamloo, A., Boroumand, A., & Mofrad, M. R. K. (2021). Drug delivery and adhesion of magnetic nanoparticles coated nanoliposomes and microbubbles to atherosclerotic plaques under magnetic and ultrasound fields. *Engineering Applications of Computational Fluid Mechanics*, 15(1), 1703–1725. doi: 10.1080/19942060.2021.1989042

[6] Eid, K. A. M., & Azzazy, H. M. E. (2014). Sustained broad-spectrum antibacterial effects of nanoliposomes loaded with silver nanoparticles. *Nanomedicine (Lond)*, 9(9), 1301–1310. doi: 10.2217/NNM.13.89

[7] Cheraghi, M., Negahdari, B., Daraee, H., & Eatemadi, A. (2017). Heart Targeted Nanoliposomal/Nanoparticles Drug Delivery: An Updated Review. *Biomedicine & Pharmacotherapy*, 86, 316–323. doi: 10.1016/J.BIOPHA.2016.12.009

[8] Bonifácio, B. V., Silva, D. P. B., Ramos, M. A. D. S., Negri, K. M. S., Bauab, M. T., & Chorilli, M. (2013). Nanotechnology-based drug delivery systems and herbal medicines: A Review. *International Journal of Nanomedicine*, 9(1), 1–15. doi: 10.2147/IJN.S52634

[9] Pulit-Prociak, J., Grabowska, A., Chwastowski, J., Majka, T. M., & Banach, M. (2019). Safety of the application of nanosilver and nanogold in topical cosmetic preparations. *Colloids and Surfaces B: Biointerfaces*, 183, 110416. doi: 10.1016/J.COLSURFB.2019.110416

[10] Mondéjar-López, M., López-Jiménez, A. J., Abad-Jordá, M., Rubio-Moraga, A., Ahrazem, O., Gómez-Gómez, L., & Niza, E. (2021). Biogenic Silver Nanoparticles From Iris Tuberosa As Potential Preservative In Cosmetic Products. *Molecules*, 26(15), 1–12. doi: 10.3390/Molecules26154696

[11] Lee, H. J., Kwon, H. K., Kim, H. S., Kim, M. Il, & Park, H. J. (2019). Hair Growth Promoting Effect Of 4HGF Encapsulated With PGA Nanoparticles (PGA-4HGF) by B-Catenin Activation and its Related Cell Cycle Molecules. *International Journal of Molecular Sciences*, 20(14). doi: 10.3390/Ijms20143447

[12] Amnuaikit, T., Rajagopal, R. S., Nilsuwan, K., & Benjakul, S. (2024). Enhancement of physical appearance, skin permeation, and odor reduction using liposome of hydrolyzed salmon collagen for cosmetic products. *Scientifica*, 2024, 7843660, 14 pages

[13] Rehman, F. U. (2019). Scope of nanotechnology in cosmetics: dermatology and skin care products. *J. Med. Chem. Sci.*, (September 2018). doi: 10.26655/Jmchemsci.2019.6.2

[14] Randad, M., Shrinivas, S., & Bachelor, H. L. D. (2022). Preparation and evaluation of hair serum. *International Journal of Advances in Engineering and Management*, 4(6), 2389.

[15] Hidayah, H., Kusumawati, A. H., Sahevtiyani, S., & Amal, S. (2021). Literature review article: aktivitas antioksidan formulasi serum wajah dari berbagai tanaman. *Journal of Pharmacopolium*, 4(2), 75–80.

[16] Sawiji, R. T., Rumbory, S., Pramita, D. A., Cahyaningrum, W., Fanny, N. P., Dewi, S., … Mahaganesha, F. (2024). Pengaruh variasi konsentrasi gelling agent (xanthan gum dan carbopol) pada sediaan serum dengan bahan aktif retinoic acid. *Acta Holistica Pharmaciana*, 6(1), 1–10. doi: 10.62857/AHP.V6I1.157

[17] Hermawan, A. V., & Susanti, A. (2022). Serum kulit manggis dan beras putih sebagai antiaging dan brightening. *Garina*, 14(1), 43–60. Retrieved from https://garina.org/index.php/journal/article/view/57

[18] Satrianingrum, A., Sari, G. K., & Pistanty, M. A. (2023). Serum Antibacterial Activity Test of Chinese Betel Extract (Peperomia Pellucida) Against Staphylococcus Aureus Bacteria. *Pratama Medika : Jurnal Kesehatan*, 2(1), 66–82. doi: 10.56480/PRATAMAMEDIKA.V2I1.938

[19] Baptista, S., Pereira, J. R., Guerreiro, B. M., Baptista, F., Silva, J. C., & Freitas, F. (2023). Cosmetic emulsion based on the fucose-rich polysaccharide fucopol: bioactive properties and sensorial evaluation. *Colloids and Surfaces B: Biointerfaces*, 225, 113252. doi: 10.1016/J.COLSURFB.2023.113252

[20] Syarifah, A., Budiman, A., & Nazilah, S. A. (2021). Formulation And Antioxidant Activity Of Serum Gel Of Ethyl Acetate Fraction From Musa X Paradisiaca L. *Proceedings of The 4th International Conference On Sustainable Innovation 2020–Health Science and Nursing (Icosihsn 2020)*, 33, 310–315. doi: 10.2991/AHSR.K.210115.066

[21] Wijianto, B., & Pratiwi, L. (2024). Serum of extract onchidium typhae uses hydroxyethyl cellulose and carboxymethyl cellulose natrium base as antioxidant. *Medical Sains : Jurnal Ilmiah Kefarmasian*, 9(1), 363–372. doi: 10.37874/MS.V9I1.1113

[22] Article, O., Noralita, K., Gumilar, B., Yuliani, H., & Dwiastuti, R. (2023). Optimization and physical characterization of quercetin nanoemulgel formula as an antibacterial agent. *International Journal of Applied Pharmaceutics*. doi: 10.22159/Ijap.2023v15i1.46737

[23] Nabilla, C. N., Andriyanto, & Subangkit, M. (2024). View of efek potensial sari buah apel (malus domestica) sebagai penumbuh rambut pada tikus (Rattus Norvegicus). *Jurnal Veteriner dan Biomedis*. 2(1), 29-34. doi: 10.29244/jvetbiomed.2.1.29-34.

[24] Collins, E., Rollando, & Monica, E. (2023). View Of Pembuatan Serum Penumbuh Rambut Kombinasi Minyak Kemiri (Aleurites Moluccanus) Dan Ekstrak Buah Apel (Pyrus Malus L.). *Jurnal Farmasi Ma Chung: Sains Teknologi Dan Klinis Komunitas*. 1(1), 32-41. doi: 10.33479/jfmc.v1i(1).6

[25] Dahiya, M., & Dureja, H. (2018). Recent developments in the formulation of nanoliposomal delivery systems. *Current Nanomaterials*, 3(2), 62–74. doi: 10.2174/2405461503666180821093033

[26] Stark, W. J., Stoessel, P. R., Wohlleben, W., & Hafner, A. (2015). Industrial Applications Of Nanoparticles. *Chemical Society Reviews*, 44(16), 5793–5805. doi: 10.1039/C4CS00362D

[27] Bhatia, S. (2016). Nanoparticles types, classification, characterization, fabrication methods and drug delivery applications. *Natural Polymer Drug Delivery Systems*, 33–93. doi: 10.1007/978-3-319-41129-3_2

[28] Hickey, J. W., Santos, J. L., Williford, J. M., & Mao, H. Q. (2015). Control Of Polymeric Nanoparticle Size To Improve Therapeutic Delivery. *Journal of Controlled Release*, 219, 536–547. doi: 10.1016/J.JCONREL.2015.10.006

[29] Schneider-Futschik, E. K., & Reyes-Ortega, F. (2021). Advantages And Disadvantages Of Using Magnetic Nanoparticles For The Treatment Of Complicated Ocular Disorders. *Pharmaceutics*, 13(8), 1–16. doi: 10.3390/Pharmaceutics13081157

[30] Alim, S., Vejayan, J., Yusoff, M. M., & Kafi, A. K. M. (2018). Recent uses of carbon nanotubes & gold nanoparticles in electrochemistry with application in biosensing: A Review. *Biosensors and Bioelectronics*, 121, 125–136. doi: 10.1016/J.BIOS.2018.08.051

[31] Bilan, R., Nabiev, I., & Sukhanova, A. (2016). Quantum dot-based nanotools for bioimaging, diagnostics, and drug delivery. *Chembiochem*, 17(22), 2103–2114. doi: 10.1002/CBIC.201600357

[32] Carvalho, M. R., Reis, R. L., & Oliveira, J. M. (2020). Dendrimer nanoparticles for colorectal cancer applications. *Journal of Materials Chemistry B*, 8(6), 1128–1138. doi: 10.1039/C9tb02289a

[33] Jamkhande, P. G., Ghule, N. W., Bamer, A. H., & Kalaskar, M. G. (2019). Metal nanoparticles synthesis: an overview on methods of preparation, advantages and disadvantages, and applications. *Journal of Drug Delivery Science and Technology*, 53, 101174. doi: 10.1016/J.JDDST.2019.101174

[34] Miere, F., Fritea, L., Cavalu, S., & Vicaș, S. I. (2020). Formulation, characterization, and advantages of using liposomes in multiple therapies. *Pharmacophore*, 11(3–2020), 1–12. Retrieved from https://pharmacophorejournal.com/article/formulation-characterization-and-

advantages-of-using-liposomes-in-multiple-therapies?html

[35] Demirci, M., Caglar, M. Y., Cakir, B., & Gülseren, I. (2017). Encapsulation By Nanoliposomes. *Nanoencapsulation Technologies for the Food and Nutraceutical Industries*, 74–113. doi: 10.1016/B978-0-12-809436-5.00003-3

[36] Khorasani, S., Danaei, M., & Mozafari, M. R. (2018). Nanoliposome technology for the food and nutraceutical industries. *Trends In Food Science & Technology*, 79, 106–115. doi: 10.1016/J.TIFS.2018.07.009

[37] Kocic, H., Stankovic, M., Tirant, M., Lotti, T., & Arsic, I. (2020). Favorable effect of creams with skimmed donkey milk encapsulated in nanoliposomes on skin physiology. *Dermatologic Therapy*, 33(4), E13511. doi: 10.1111/DTH.13511

[38] Saewan, N., Jimtaisong, A., Panyachariwat, N., & Chaiwut, P. (2023). In Vitro and In Vivo Anti-Aging Effect of Coffee Berry Nanoliposomes. *Molecules*, 28(19). doi: 10.3390/Molecules28196830

[39] Costa, C., Fernandes, B., Guimarães, D., Nogueira, E., Martins, M., Matamá, T., & Cavaco-Paulo, A. (2021). Comparing the delivery to the hair bulb of two fluorescent molecules of distinct hydrophilicities by different nanoparticles and a serum formulation. *International Journal of Pharmaceutics*, 602, 120653. doi: 10.1016/J.IJPHARM.2021.120653

[40] Tansathien, K., Chareanputtakhun, P., Ngawhirunpat, T., Opanasopit, P., & Rangsimawong, W. (2021). Hair growth promoting effect of bioactive extract from deer antler velvet-loaded niosomes and microspicules serum. *International Journal Of Pharmaceutics*, 597, 120352. doi: 10.1016/J.IJPHARM.2021.120352

[41] Takabayashi, Y., Nambu, M., Ishihara, M., Kuwabara, M., Fukuda, K., Nakamura, S., … Kiyosawa, T. (2016). Enhanced effect of fibroblast growth factor-2-containing dalteparin/protamine nanoparticles on hair growth. *Clinical, Cosmetic and Investigational Dermatology*, 9, 127–134. doi: 10.2147/CCID.S108187

[42] Fernandes, B., Silva, R., Ribeiro, A., Matamá, T., Gomes, A. C., & Cavaco-Paulo, A. M. (2015). Improved Poly (D,L-Lactide) Nanoparticles-Based Formulation For Hair Follicle Targeting. *International Journal of Cosmetic Science*, 37(3), 282–290. doi: 10.1111/ICS.12197

[43] Kong, J., Qiang, W., Jiang, J., Hu, X., Chen, Y., Guo, Y. X., … Li, H. (2022). Safflower Oil Body Nanoparticles Deliver HFGF10 To Hair Follicles And Reduce Microinflammation To Accelerate Hair Regeneration in Androgenetic Alopecia. *International Journal of Pharmaceutics*, 616, 121537. doi: 10.1016/J.IJPHARM.2022.121537

[44] Tian, L. W., Luo, D., Chen, D., Zhou, H., Zhang, X. C., Yang, X. L., … Liu, W. (2022). Co-Delivery Of Bioactive Peptides By Nanoliposomes For Promotion of Hair Growth. *Journal of Drug Delivery Science and Technology*, 72, 103381. doi: 10.1016/J.JDDST.2022.103381

[45] Zhang, S., Zhou, H., Chen, X., Zhu, S., Chen, D., Luo, D., … Liu, W. (2024). Microneedle delivery platform integrated with codelivery nanoliposomes for effective and safe androgenetic alopecia treatment. *ACS Applied Materials and Interfaces*, 16(13), 15701–15717. doi: https://doi.org/10.1021/acsami.3c16608

[46] Xu, H. L., Chen, P. P., Wang, L. Fen, Xue, W., & Fu, T. L. (2018). Hair Regenerative Effect Of Silk Fibroin Hydrogel With Incorporation Of FGF-2-Liposome And Its Potential Mechanism In Mice With Testosterone-Induced Alopecia Areata. *Journal of Drug Delivery Science And Technology*, 48, 128–136. doi: 10.1016/J.JDDST.2018.09.006

[47] Tanriverdi, T. S., Gokce, E. H., Filiz, S. B., Kose, F. A., & Ozer, O. (2022). Protection Of Hair Color With Pomegranate Peel Extract-Loaded Liposomal Formulation: Preparation, Characterization, And Ex-Vivo Activity Studies. *Journal of Cosmetic Dermatology*, 21(11), 6292–6301. doi: 10.1111/JOCD.15254

[48] Liu, Z., He, Z., Ai, X., Guo, T., & Feng, N. (2024). Cardamonin-Loaded Liposomal Formulation For Improving Percutaneous Penetration And Follicular Delivery For Androgenetic Alopecia. *Drug Delivery and Translational Research*, 1–17. doi: 10.1007/S13346-024-01519-8/METRICS