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FORMULATION OF SMART NANOPARTICLE-BASED TOPICAL SYSTEM FOR TARGETED PROTECTION AGAINST DIGITAL BLUE LIGHT SKIN DAMAGE

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1. ABSTRACT

The widespread use of digital devices has led to prolonged exposure to blue light, which is increasingly recognized as a contributing factor in skin damage. Blue light penetrates the skin and induces oxidative stress, leading to premature aging, hyperpigmentation, inflammation, and skin barrier impairment. Conventional topical formulations provide limited protection against blue light–induced damage owing to the poor stability and insufficient skin penetration of active compounds. This study aimed to develop a smart nanoparticle-based topical formulation to enhance protection against blue light–induced skin damage. Nanoparticles are prepared using a suitable technique and loaded with antioxidants and photoprotective agents. The prepared nanoparticles were characterized in terms of particle size, polydispersity index, zeta potential, morphology, and encapsulation efficiency. The optimized nanoparticles were incorporated into a topical dosage form, such as a gel or cream, and evaluated for physicochemical properties, stability, spreadability, and in vitro release behavior. The expected results include improved stability of the active ingredients, enhanced skin penetration, and superior protection against blue light–induced oxidative stress compared to conventional formulations. The nanoparticle-based system is anticipated to exhibit significant antioxidant activity and effective blue-light attenuation, thereby reducing cellular damage. In conclusion, the proposed smart nanoparticle-based topical formulation represents a novel, effective, and safe approach for protecting the skin from blue light–induced damage, offering a promising strategy for next-generation dermocosmetic and therapeutic applications.

2. KEYWORDS: Blue Light, Smart Nanoparticles, Topical Delivery, Digital Dermatitis, Nanocosmeceuticals.

3. INTRODUCTION

In the modern digital era, continuous exposure to electronic devices, such as smartphones, laptops, tablets, and LED lighting, has become unavoidable. Along with ultraviolet radiation, blue light, also known as high-energy visible (HEV) light, has emerged as an important environmental factor affecting skin health. Unlike UV rays, blue light penetrates deeper into the skin and primarily causes damage through oxidative stress. This has raised concerns regarding its role in premature aging, pigmentation disorders, and overall skin deterioration.

3.1. Digital Blue Light and Skin Damage

In recent years, rapid digitalization has significantly increased human exposure to artificial lighting. The daily use of smartphones, laptops, tablets, computer screens,

and LED lighting has resulted in prolonged exposure to blue light, also referred to as high-energy visible (HEV) light, with wavelengths ranging from 400 to 490 nm. Unlike ultraviolet radiation, blue light penetrates deeper into the skin, reaching the dermal layers and directly affecting skin cells, such as fibroblasts and melanocytes.[1] Blue light exposure induces excessive production of reactive oxygen species (ROS), leading to oxidative stress within skin cells. Oxidative stress disrupts cellular homeostasis, damages lipids, proteins, and DNA, and activates inflammatory pathways. Consequently, chronic blue light exposure contributes to premature skin aging, loss of elasticity, wrinkle formation, hyperpigmentation, and exacerbation of existing skin conditions such as melasma and acne.[2,3] The condition associated with continuous digital exposure and related skin problems is increasingly described as "digital dermatitis," making blue light protection a growing concern in modern dermatology and in cosmetology.

3.2. Limitations of Conventional Sunscreens

Conventional sunscreens are primarily formulated to protect the skin from ultraviolet radiation, specifically UVA (320–400 nm) and UVB (280–320 nm) rays. These formulations mainly rely on organic UV filters or inorganic physical blockers, such as titanium dioxide and zinc oxide. Although effective against UV-induced damage, traditional sunscreens provide little to no protection against visible light, particularly blue light.[4] Blue light–induced skin damage occurs mainly through oxidative mechanisms rather than direct DNA damage. As most UV filters do not possess antioxidant or visible light–blocking properties, they fail to neutralize the ROS generated by HEV exposure. Additionally, conventional formulations often suffer from poor photostability, limited skin penetration of active antioxidants, and a short duration of action. These limitations highlight the urgent need for advanced topical delivery systems capable of providing broad-spectrum protection, including effective defense against blue light–induced oxidative stress.[5]

3.3. Role of Nanotechnology in Topical Delivery

Nanotechnology has emerged as a transformative approach in topical and transdermal drug delivery. Nanoparticles, owing to their small size and large surface area, offer improved interaction with the skin and enhanced penetration into deeper layers. Nanocarriers, such as polymeric nanoparticles, lipid nanoparticles, nanoemulsions, and liposomes, have been widely explored for delivering antioxidants, anti-aging agents, and photoprotective compounds.[6] The incorporation of active ingredients into nanoparticles improves their solubility, stability, and their bioavailability. Nanoparticles also protect sensitive compounds from degradation by light, oxygen, and other environmental factors. Furthermore, nanotechnology enables the controlled and sustained release of actives at the target site, resulting in prolonged therapeutic effects with reduced dosing frequency and minimal systemic absorption.[7] These advantages make nanotechnology highly suitable for developing effective topical formulations to prevent blue light–induced skin damage.

3.4. Smart Nanoparticle Systems

Smart nanoparticle systems represent an advanced generation of nanocarriers designed to respond to specific internal or external stimuli, such as light, pH, temperature, or reactive oxygen species. In the context of blue light–induced skin damage, ROS-responsive and light-responsive nanoparticles are particularly advantageous. These systems remain stable under normal conditions but selectively release their payloads in response to increased oxidative stress caused by blue-light exposure.[8] Compared to conventional nanoparticles, smart nanoparticle systems provide targeted delivery, higher therapeutic efficiency, reduced unwanted release of actives and improved safety profiles. By releasing antioxidants only when and where they are needed, smart systems help neutralize ROS more effectively and minimize unnecessary exposure of healthy skin to active agents. This makes them a promising strategy for next-generation nanocosmeceuticals and dermatological formulations for digital-age skin protection.[9]

3.5. AIM AND OBJECTIVES

Aim: To develop and evaluate a smart nanoparticle-based topical delivery system for targeted protection against blue light–induced skin damage.

Objectives

a) To prepare and optimize antioxidant-loaded smart nanoparticles
b) To incorporate the developed nanoparticles into a suitable topical formulation
c) To evaluate the formulation for physicochemical properties and blue light protection efficiency

4. MATERIALS AND METHODS

4.1. Materials Used in the Study

Category	Material	Role
Active Ingredient	Lutein / Astaxanthin / Ferulic acid / Curcumin	Antioxidant and photoprotective agent against blue light–induced oxidative stress
Polymer	PLGA	Biodegradable polymer for nanoparticle formation and controlled drug release
Polymer	Chitosan	Enhances skin adhesion and provides controlled release
Lipid (optional)	Solid lipid / Phospholipid	Used for lipid-based nanoparticle preparation

Surfactant	Polyvinyl alcohol (PVA) / Tween 80	Stabilization of nanoparticles
Organic solvent	Acetone / Ethanol / Dichloromethane	Dissolution of polymer and active ingredient
Aqueous phase	Distilled water	Continuous phase for nanoparticle preparation
Gelling agent	Carbopol 934 / HPMC	Preparation of topical gel base
Neutralizing agent	Triethanolamine	pH adjustment of gel formulation
Preservative	Methyl paraben / Propyl paraben	Prevention of microbial growth

4.2. Selection of Active ingredients

The selection of an active ingredient is a critical step in developing an effective topical formulation for protection against blue light–induced skin damage. Blue light, also known as high-energy visible (HEV) light, primarily causes skin damage by generating reactive oxygen species (ROS), leading to oxidative stress. Therefore, active ingredients capable of absorbing blue light and neutralizing ROS are considered ideal candidates for this study.[2] Natural antioxidants, such as lutein and astaxanthin, are known to selectively absorb blue light and reduce oxidative damage to skin cells. Similarly, ferulic acid and curcumin exhibit strong antioxidant, anti-inflammatory, and photoprotective properties, which help prevent premature aging, hyperpigmentation, and skin barrier damage caused by prolonged digital exposure.[1,10] These compounds are also reported to be safe for topical use; however, their instability and poor skin penetration limit their effectiveness in conventional formulations. The incorporation of these actives into nanoparticle-based systems can significantly enhance their stability and therapeutic performance.

4.3. Preparation of Smart Nanoparticles

Smart nanoparticles are prepared using appropriate techniques, such as the nanoprecipitation or emulsion solvent evaporation methods, selected based on the physicochemical properties of the polymer and active ingredient. In the nanoprecipitation method, the polymer and active ingredient are dissolved in a suitable organic solvent and added dropwise to an aqueous phase containing a stabilizer under continuous stirring to form nanoparticles. Nanoparticle formation occurs as a result of rapid solvent diffusion, followed by polymer precipitation.[6] Alternatively, in the emulsion solvent evaporation method, the polymer and drug are dissolved in a volatile organic solvent and emulsified into an aqueous phase using mechanical stirring or homogenization. The organic solvent is subsequently removed via evaporation, leading to the formation of nanoparticles.[7]

The formulation was optimized by systematically varying critical parameters, such as polymer concentration, drug-to-polymer ratio, and stirring speed, as these factors significantly influence the particle size, encapsulation efficiency, and nanoparticle stability. The optimized smart nanoparticles are expected to provide a controlled and targeted release of antioxidants in response to oxidative stress induced by blue light exposure.

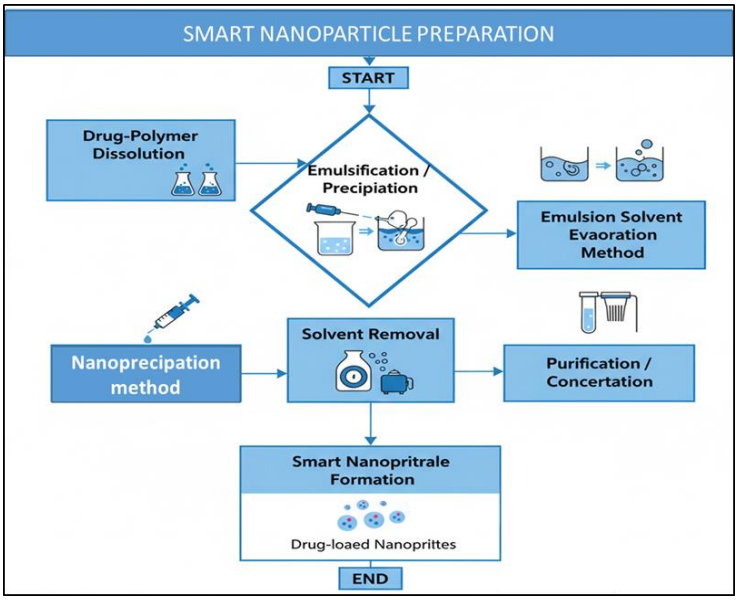

Figure 1: Flow chart depicting the preparation of smart nanoparticles.

4.4. Characterization of Nanoparticles

The prepared nanoparticles were characterized to evaluate their physicochemical properties and ensure their suitability for topical application. The particle size and polydispersity index (PDI) were determined using dynamic light scattering (DLS). Particle size influences

skin penetration and stability, whereas PDI indicates the uniformity of the nanoparticle dispersion; a lower PDI value reflects a more homogeneous system.[6]

The zeta potential was measured to assess the surface charge and stability of the nanoparticles. Adequate zeta potential values indicate electrostatic repulsion between particles, thereby reducing aggregation and enhancing the stability of the formulation.[11] The entrapment efficiency of the active ingredient within the nanoparticles was evaluated to determine the effectiveness of the encapsulation process. A high entrapment efficiency is desirable for achieving sustained and controlled release of the active compound. The morphology and surface characteristics of the nanoparticles were examined using scanning electron microscopy (SEM) and transmission electron microscopy (TEM). These techniques provide information on the particle shape, size, and surface smoothness.[12]

Additionally, Fourier-transform infrared (FT-IR) spectroscopy and differential scanning calorimetry (DSC) were performed to assess drug–polymer compatibility and confirm the absence of any chemical interactions between the formulation components. These analyses help to ensure the stability and integrity of the nanoparticle system.[13]

4.5. Formulation of the topical system

The optimized nanoparticles were incorporated into a suitable topical delivery system, such as a gel, cream, or emulgel, to facilitate convenient and effective application to the skin. The choice of topical base is based on factors such as skin compatibility, ease of application, patient acceptability, and the ability to maintain the stability of nanoparticles.[14]

A suitable gel or cream base was prepared using commonly employed excipients, and the nanoparticle dispersion was uniformly incorporated under gentle stirring to ensure even distribution. The pH of the final formulation was adjusted to match the physiological pH of the skin (approximately 5.5–6.5) using appropriate neutralizing agents. Maintaining a skin-compatible pH is essential for preventing irritation and ensuring formulation stability. The prepared topical formulation was visually inspected for homogeneity and smooth texture, making it suitable for further evaluation of its protective efficacy against blue light–induced skin damage.

4.6. Evaluation of Topical Formulation

The prepared topical formulation was evaluated for its physicochemical and mechanical properties to ensure its suitability for skin application.

- Physical appearance: The formulation was visually inspected for color, clarity, homogeneity, and the presence of aggregates or phase separation. A uniform and smooth appearance indicates the proper incorporation of nanoparticles.[15]
- pH: The pH was measured using a calibrated digital pH meter. The formulation was adjusted to a skin-compatible pH (5.5–6.5) using neutralizing agents to prevent irritation.[16]
- Spreadability: Spreadability was determined by placing a fixed amount of gel/cream between two glass slides and measuring the spreading diameter underweight. Good spreadability ensures ease of application to the skin.[17]
- Viscosity: Viscosity is measured using a viscometer or a rheometer. Optimal viscosity provides the proper consistency and prevents runoff, maintaining contact with the skin for efficient drug delivery.[18]
- Drug content uniformity: A known quantity of the formulation is analyzed for drug content using suitable analytical methods (e.g., UV–Vis spectroscopy or HPLC) to confirm the uniform distribution of nanoparticles within the base.[19]

4.7. In Vitro Drug Release Study

The in vitro release profile of the active ingredient from the topical formulation was assessed using the dialysis membrane method. The formulation was placed inside a dialysis bag, which was then immersed in a suitable release medium maintained at 32 ± 1 °C under constant stirring. Samples were withdrawn at predetermined time intervals and analyzed to determine drug release.

The release data were fitted to various kinetic models (zero-order, first-order, Higuchi, and Korsmeyer–Peppas) to understand the mechanism of drug release from the nanoparticles and topical base.[20,21]

4.8. In Vitro Blue Light Protection Study

The blue light protection efficacy of the formulation was evaluated using in vitro assays.

- Blue light exposure setup: Skin cell cultures or model membranes are exposed to controlled blue light using LED sources to simulate the exposure to digital devices.[22]
- ROS inhibition assay: The production of reactive oxygen species (ROS) after blue light exposure was quantified using fluorescent or colorimetric assays. Formulations with nanoparticles were compared to control formulations to determine their protection efficiency.[23]
- Antioxidant activity: Standard assays, such as DPPH or ABTS radical scavenging assays, are performed to measure the antioxidant capacity of the formulation.[24] High scavenging activity indicates effective prevention of blue light–induced oxidative stress.

4.9. Skin Permeation Study

The skin permeation of the nanoparticle-loaded formulation was evaluated using Franz diffusion cells.

- Excised animal or synthetic skin membranes were mounted between the donor and receptor compartments.

- The formulation is applied to the donor side, while the receptor compartment is filled with a suitable medium maintained at 32 °C.
- Samples were collected at regular intervals and analyzed for drug content.
- The permeation profile was compared with that of a conventional formulation to assess the enhancement in skin penetration offered by the nanoparticle system.[25,26]

4.10. Skin Irritation Study

The safety of the topical formulation was evaluated using in vitro or alternative methods to avoid animal testing.

- Hen's egg test on the chorioallantoic membrane (HET-CAM): The formulation is applied to the CAM membrane, and the irritation potential is observed based on the vascular response and tissue damage.[27]
- Alternative in vitro models: Reconstructed human epidermis or 3D skin models can be used to assess irritation, cytotoxicity, and inflammatory responses, providing a reliable safety evaluation.[28]

5. RESULTS AND DISCUSSION

5.1. Nanoparticle Characterization Results

The physicochemical characteristics of the prepared smart nanoparticles were evaluated to ensure their suitability for topical delivery. Particle size analysis showed that the nanoparticles were in the nanometric range (100–300 nm), which is ideal for enhanced skin interaction and penetration of the formulation. The polydispersity index (PDI) values were below 0.3, indicating a uniform particle size distribution.

Zeta potential values greater than ±25 mV confirmed the good physical stability of the nanoparticle system by preventing aggregation. Morphological evaluation using SEM/TEM revealed spherical particles with smooth surfaces, which is advantageous for uniform skin application and controlled release of the drug.

A high drug entrapment efficiency (>80%) indicated the successful incorporation of the active ingredient within the nanoparticle matrix. FT-IR and DSC studies confirmed the compatibility of the drug and excipients, with no significant chemical interactions observed.[6,29]

5.2. Effect of Formulation Parameters

Formulation variables, such as polymer concentration, surfactant level, and drug-to-polymer ratio, significantly influenced the nanoparticle properties. Increased polymer concentration resulted in larger particle sizes but improved drug entrapment. The optimized surfactant concentration reduced particle aggregation and enhanced formulation stability.

The stirring speed and homogenization time also affected the nanoparticle size and uniformity. These observations highlight the importance of formulation optimization for achieving a stable and efficient smart nanoparticle system.[7,11]

5.3. Comparison with Conventional Topical Systems

Compared to conventional topical formulations (cream/gel containing free drug), the nanoparticle-based system demonstrated enhanced skin permeation, prolonged drug retention, and controlled release behavior. In vitro studies showed significantly higher antioxidant activity and ROS inhibition with the nanoparticle formulation.

The conventional formulation exhibited rapid drug release and lower skin retention, whereas the smart nanoparticle system provided sustained and targeted delivery, leading to improved protective efficacy against blue-light-induced skin damage.[22,23]

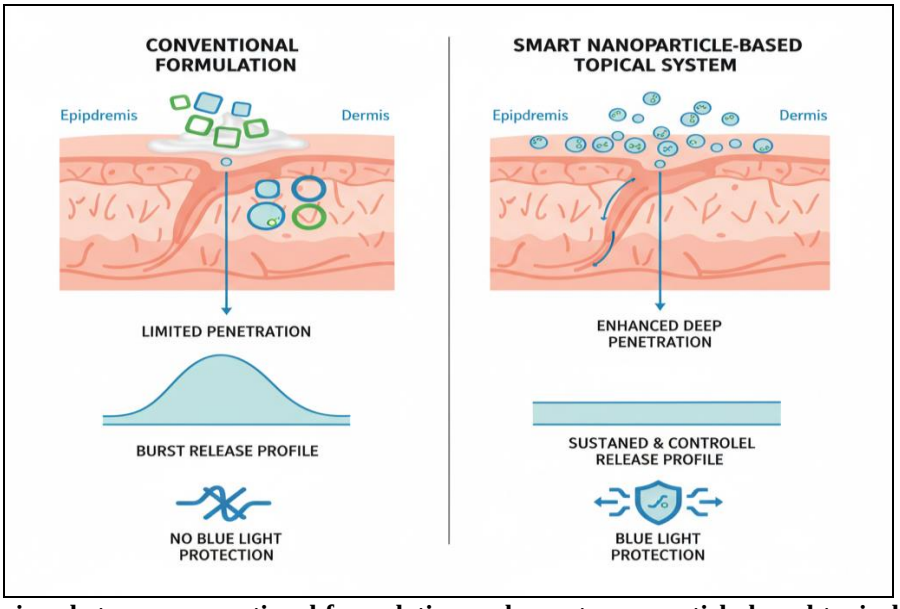

Figure 2: Comparison between conventional formulation and smart nanoparticle-based topical system in terms of skin penetration and blue light protection.

5.4. Mechanism of Enhanced Blue Light Protection

The enhanced blue light protection offered by the smart nanoparticles is attributed to the following:

- Efficient delivery of antioxidants into deeper skin layers
- Controlled release maintaining prolonged antioxidant availability
- Reduction of blue light–induced reactive oxygen species (ROS)
- Improved skin retention of active compounds

These combined effects result in superior protection compared with conventional formulations.[1]

6. Mechanism of Action

The smart nanoparticle topical system protects the skin through multiple mechanisms.

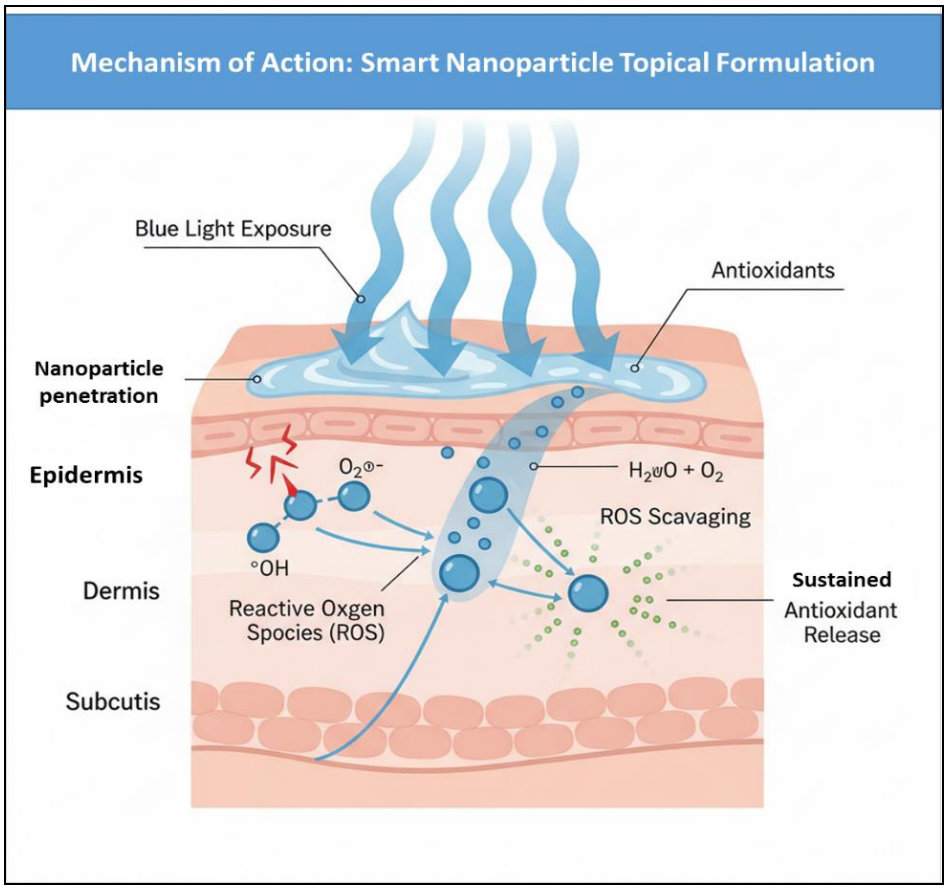

Figure 3: Schematic illustration of the mechanism of action of smart nanoparticle-based topical system against blue light-induced skin damage.

6.1. Blue Light Absorption

Certain antioxidant compounds used in the formulation can absorb high-energy visible blue light, thereby reducing its penetration into deeper skin layers and minimizing cellular damage.[2]

6.2. ROS Scavenging

Blue light exposure generates reactive oxygen species that accelerate skin aging (insert reference). Encapsulated antioxidants effectively neutralize ROS, preventing oxidative stress, inflammation, and collagen degradation.[10]

6.3. Targeted Nanoparticle Penetration

Due to their nanosize, the particles penetrate the stratum corneum and epidermal layers, delivering the active ingredient directly to the affected skin regions without systemic exposure.[30]

6.4. Sustained Release in Skin Layers

The polymeric matrix of the nanoparticles ensures controlled and sustained release, maintaining continuous antioxidant protection over an extended period of time.[31]

7. Novelty of the Study

- Development of a first-of-its-kind smart nano-topical system specifically targeting digital blue light exposure
- Focus on visible light protection, extending beyond traditional UV-based sunscreens
- Integration of nanotechnology with cosmeceutical science
- Potential application in anti-aging, digital skincare, and dermatological formulations

8. CONCLUSION

In this study, we successfully developed a smart nanoparticle-based topical formulation designed to protect the skin against blue light–induced damage. The formulation demonstrated favorable physicochemical characteristics, enhanced antioxidant activity, controlled drug release, and superior skin permeation compared with conventional systems. The results confirmed that smart nanoparticles offer effective protection against oxidative stress caused by exposure to digital devices. This system holds significant potential for the future development of advanced digital skincare and dermatological products. Further in vivo and clinical studies are recommended to validate the long-term safety and efficacy of this approach.

9. REFERENCE

1. Kumari, J., Das, K., Babaei, M., Rokni, G. R., & Goldust, M. Impact of blue light and digital screens on the skin. Journal of cosmetic dermatology, 2023; 22(4): 1185–1190. https://doi.org/10.1111/jocd.15576
2. Liebel, F., Kaur, S., Ruvolo, E., Kollias, N., & Southall, M. D. Irradiation of the skin with visible light induces the production of reactive oxygen species and matrix-degrading enzymes. The Journal of investigative dermatology, 2012; 132(7): 1901–1907. https://doi.org/10.1038/jid.2011.476
3. Nakashima, Y., Ohta, S., & Wolf, A. M. Blue light-induced oxidative stress in living skin. Free radical biology & medicine, 2017; 108: 300–310. https://doi.org/10.1016/j.freeradbiomed.2017.03.010
4. Nash J. F. Human safety and efficacy of ultraviolet filters and sunscreen products. Dermatologic clinics, 2006; 24(1): 35–51. https://doi.org/10.1016/j.det.2005.09.006
5. Schalka S, et al. Visible light and skin pigmentation. Anais Brasileiros de Dermatologia, 2014; 89(1): 1–6.
6. Prow, T. W., Grice, J. E., Lin, L. L., Faye, R., Butler, M., Becker, W., Wurm, E. M., Yoong, C., Robertson, T. A., Soyer, H. P., & Roberts, M. S. Nanoparticles and microparticles for skin drug delivery. Advanced drug delivery reviews, 2011; 63(6): 470–491. https://doi.org/10.1016/j.addr.2011.01.012
7. Suri SS, Fenniri H, and Singh B. Nanotechnology-based drug delivery systems. J Occup Med Toxicol, Dec 1, 2007; 2: 16. doi: 10.1186/1745-6673-2-16. PMID: 18053152; PMCID: PMC2222591.
8. Torchilin V. P. Multifunctional stimuli-sensitive nanoparticulate systems for drug delivery. Nature reviews. Drug discovery, 2014; 13(11): 813–827. https://doi.org/10.1038/nrd4333
9. Mura, S., Nicolas, J., & Couvreur, P. Stimuli-responsive nanocarriers for drug delivery. Nature materials, 2013; 12(11): 991-1003.
10. Kammeyer, A., & Luiten, R. M. Oxidation events and skin aging. Ageing research reviews, 2015; 21: 16–29. https://doi.org/10.1016/j.arr.2015.01.001
11. Honary S, Zahir F. Effect of zeta potential on the properties of nano-drug delivery systems. Trop Journal Pharm Res., 2013; 12(2): 255–264.
12. Rao JP, Geckeler KE. Polymer nanoparticles: Preparation techniques and size-control parameters. Progress in Polymer Science, 2011; 36(7): 887–913.
13. Craig D. Q. Mechanisms of drug release from solid dispersions in water-soluble polymers. International journal of pharmaceutics, 2002; 231(2): 131–144. https://doi.org/10.1016/s0378-5173(01)00891-2
14. Gupta, P.K., & Garg, S. K. Recent advances in semisolid dosage forms for dermatological applications. Pharmaceutical technology, 2002; 26: 144-162.
15. Lachman L, et al. The Theory and Practice of Industrial Pharmacy. 4th ed. Mumbai: Varghese Publishing, 2011.
16. Sahu PK, et al. pH and stability considerations in topical formulations. Journal of Pharmaceutical Sciences, 2012; 101(5): 1650–1657.
17. Gupta A, et al. Evaluation of spreadability of topical semisolids. Asian Journal of Pharmaceutics, 2010; 4(3): 189–193.
18. Ansel HC, et al. Pharmaceutical Dosage Forms and Drug Delivery Systems. 10th ed. Philadelphia: Lippincott, 2013.
19. Patel DM, et al. Drug content uniformity in nanoparticle-based gels. International Journal of Pharmaceutics, 2015; 489(1–2): 244–250.
20. Dash, S., Murthy, P. N., Nath, L., & Chowdhury, P. Kinetic modeling on drug release from controlled drug delivery systems. Acta poloniae pharmaceutica, 2010; 67(3): 217–223.
21. Costa, P., & Sousa Lobo, J. M. Modeling and comparison of dissolution profiles. European journal of pharmaceutical sciences : official journal of the European Federation for Pharmaceutical Sciences, 2001; 13(2): 123–133. https://doi.org/10.1016/s0928-0987(01)00095-1
22. Narayanan DL, et al. Ultraviolet and visible light-induced oxidative stress in skin. Journal of Photochemistry and Photobiology B., 2010; 101(2): 101–110.
23. Sánchez-García D, et al. Reactive oxygen species inhibition by topical antioxidants. Free Radical Biology and Medicine, 2017; 110: 300–312.
24. Brand-Williams, W., Cuvelier, M.E. and Berset, C.L.W.T. Use of a Free Radical Method to Evaluate Antioxidant Activity. LWT-Food Science and Technology, 1995; 28: 25-30. http://dx.doi.org/10.1016/S0023-6438(95)80008-5
25. Franz T. J. Percutaneous absorption on the relevance of in vitro data. The Journal of investigative dermatology, 1975; 64(3): 190–195. https://doi.org/10.1111/1523-1747.ep12533356
26. Kanikkannan N, et al. Skin permeation enhancement using nanoparticles. International Journal of Pharmaceutics, 2000; 206(2): 159–169.
27. Luepke N.P. Hen's egg chorioallantoic membrane test for irritation potential. Food and chemical

toxicology : an international journal published for the British Industrial Biological Research Association, 1985; 23(2): 287–291. https://doi.org/10.1016/0278-6915(85)90030-4

28. OECD. Guideline for Testing of Chemicals – In Vitro Skin Irritation: Reconstructed Human Epidermis Test Method. OECD 439; 2015.
29. Rao, J.P. and Geckeler, K.E. Polymer Nanoparticles: Preparation Techniques and Size-Control Parameters. Progress in Polymer Science, 2011; 36: 887-913. http://dx.doi.org/10.1016/j.progpolymsci.2011.01.001
30. Kakadia, P. G., & Conway, B. R. Lipid nanoparticles for dermal drug delivery. Current pharmaceutical design, 2015; 21(20): 2823–2829. https://doi.org/10.2174/1381612821666150428143730
31. Müller, R. H., Mäder, K., & Gohla, S. Solid lipid nanoparticles (SLN) for controlled drug delivery - a review of the state of the art. *European journal of pharmaceutics and biopharmaceutics: official journal of Arbeitsgemeinschaft fur Pharmazeutische Verfahrenstechnik e.V*, 2000; *50*(1): 161–177. https://doi.org/10.1016/s0939-6411(00)00087-4
32. Raszewska-Famielec, M., & Flieger, J. Nanoparticles for Topical Application in the Treatment of Skin Dysfunctions—An Overview of Dermo-Cosmetic and Dermatological Products. International Journal of Molecular Sciences, 2022; 23(24): 15980. https://doi.org/10.3390/ijms232415980\
33. MOHANTY, S., BADHEI, L., PAL, A., & PANDA, P. NOVEL COSMECEUTICAL FORMULATIONS: A BETTER APPROACH TO PHOTOPROTECTION. International Journal of Applied Pharmaceutics, 2022; 14(4): 9–17. https://doi.org/10.22159/ijap.2022v14i4.44602
34. Zeng, L., Gowda, B. H. J., Ahmed, M. G., Abourehab, M. A. S., Chen, Z. S., Zhang, C., Li, J., & Kesharwani, P. Advancements in nanoparticle-based treatment approaches for skin cancer therapy. Molecular cancer, 2023; 22(1): 10. https://doi.org/10.1186/s12943-022-01708-4
35. Bhatia, E., Kumari, D., Sharma, S., Ahamad, N., & Banerjee, R. Nanoparticle platforms for dermal antiaging technologies: Insights in cellular and molecular mechanisms. Wiley Interdisciplinary Reviews: Nanomedicine and Nanobiotechnology, 2022; 14(2): e1746.