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Formulation and Evaluation of Herbal Nanoemulgel Sunscreen Containing Green Tea (*Camellia sinensis*) and Pomegranate (*Punica granatum*) Peel Extracts

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ABSTRACT

Prolonged, unprotected exposure to solar ultraviolet (UV) radiation contributes to sunburn, photoaging and skin cancer. While inorganic filters such as zinc oxide give broad-spectrum protection, they are often associated with a visible white cast, prompting interest in combining them with plant-derived antioxidants that can boost efficacy while improving cosmetic acceptability. In this study, a herbal nanoemulgel was formulated by incorporating zinc oxide together with ethanolic (70%) macerated extracts of green tea (Camellia sinensis) leaves and pomegranate (Punica granatum) peel into a Carbopol 940 hydrogel base. Both extracts were screened for their principal phytoconstituents, and the finished formulation was characterised for physical appearance, pH, viscosity, spreadability, in-vitro sun protection factor (SPF, Mansur spectrophotometric method) and drug-excipient compatibility (FTIR). The optimised nanoemulgel was a smooth, glossy, greenish-white semisolid with a pH of 4.8, a viscosity of 1993 cP (spindle 6, 30 rpm, 25 °C), a spreadability of 6.92 ± 0.18 cm, and an in-vitro SPF of 30.50, placing it in the SPF 30+ category. Phytochemical screening confirmed flavonoids, phenolics, tannins, saponins and terpenoids in both extracts, and FTIR spectra showed no shift in the principal functional-group peaks of the drug-excipient mixture, confirming compatibility. These results indicate that the herbal nanoemulgel is a cosmetically elegant and photoprotective alternative to conventional sunscreens, meriting further stability and in-vivo evaluation.

Introduction

Sunscreens are topical products that limit UV-induced skin damage by reflecting, absorbing or scattering incident radiation. UV-A drives photoaging by penetrating into the dermis, while UV-B is the principal cause of sunburn and DNA damage; UV-C is largely filtered by the atmosphere before reaching the skin [1,4]. Conventional formulations rely on inorganic filters (e.g., zinc oxide, titanium dioxide) or organic chemical absorbers. Inorganic filters are photostable and generally well tolerated but, at larger particle sizes, can leave a visible white residue, while some chemical filters raise concerns about irritation and systemic absorption [3,5,9].

Botanicals such as green tea and pomegranate peel are increasingly explored as "UV boosters" alongside synthetic filters. Green tea is rich in catechins, principally epigallocatechin gallate (EGCG), which scavenge free radicals, while pomegranate peel supplies ellagic acid and tannins that support collagen preservation and DNA protection [10-14]. Combining such antioxidants with an inorganic filter in a nanoemulgel platform - a nanoemulsion dispersed within a hydrogel network - can, in principle, improve spreadability, reduce the effective filter load, and yield a lighter, more elegant sensory profile than conventional creams [17,18].

The present work formulates and evaluates such a system, combining zinc oxide with green tea and pomegranate peel extracts in a Carbopol 940 nanoemulgel, and characterises it for physicochemical quality, phytochemical content and in-vitro sunscreen performance.

Anatomy of the Skin

The skin is the largest organ of the body. It serves as the primary line of defence against the external environment but, for the same reason, also poses a formidable barrier to topical drug and cosmetic delivery.

Its outermost layer, the stratum corneum, is a thin — 10–20 µm — matrix of keratinised cells embedded in waxy lipids that restricts the entry of external substances. Structurally, the skin is composed of three principal layers: the epidermis, the dermis and the subcutaneous tissue.

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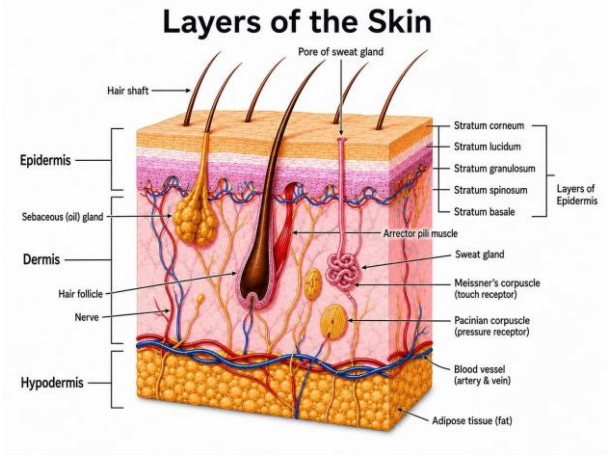

Figure 1. The three principal layers of the skin — epidermis, dermis and subcutaneous tissue.

Epidermis

The epidermis is the superficial, relatively thin outer layer of the skin, composed of stratified keratinised squamous epithelium; its thickness varies with cell size and the number of cell layers present. It can be further divided into five sublayers: the stratum corneum, stratum lucidum, stratum granulosum, stratum spinosum and stratum germinativum.

The **stratum corneum**, the most superficial of these, consists of 25–30 layers of flattened, keratin-rich keratinocytes that protect the deeper layers from injury. Beneath it lies the **stratum lucidum**, a thin, translucent layer found only in the thick skin of the palms, soles and fingertips. The **stratum granulosum** is a narrow, one- to three-cell-thick layer of spindle-shaped cells rich in keratohyalin granules containing cystine- and histidine-rich proteins. The **stratum spinosum** is a broader layer, eight to ten cells thick, in which the keratinocytes flatten and their nuclei shrink to give the cells a polygonal appearance. The deepest layer, the **stratum germinativum**, proliferates continuously to renew the epidermis and contains the melanocytes responsible for producing and distributing melanin.

Dermis

The dermis lies beneath the epidermis and is formed of connective tissue rich in collagen and elastin fibres; it also houses the blood vessels, nerves, glands and hair follicles that support the skin.

Subcutaneous tissue

The subcutaneous tissue lies deep to the dermis and, strictly speaking, is not part of the skin itself. Composed of areolar and adipose tissue, it acts as an energy store, cushions underlying structures, and contains the larger blood vessels that supply the skin.

Skin appendages

The skin also gives rise to several appendages, or derivatives, including the hair follicles, sebaceous glands, sweat (eccrine) glands, apocrine glands and nails.

Ideal Characteristics of a Nanoemulgel Sunscreen

An ideal nanoemulgel-based sunscreen is expected to satisfy a combination of photoprotective, physicochemical, biological and aesthetic criteria, summarised below.

Photoprotective efficacy

- **Broad-spectrum protection:** blocks both UVB (290–320 nm) and UVA (320–400 nm), with a critical wavelength of ≥ 370 nm.
- **Balanced UVA/UVB protection:** UVA protection factor (UVA-PF) ≥ one-third of the labelled SPF.
- **UV boosting:** incorporation of natural bioactives (e.g., green tea, pomegranate) to raise the SPF while lowering the synthetic or mineral filter load.
- **Photostability:** an area-under-curve index (AUCI) ≥ 0.80 after 120 minutes of UV exposure.
- **Water/sweat resistance:** retention of the labelled SPF after 40 minutes (water-resistant) or 80 minutes (very water-resistant) of immersion.

Physicochemical and rheological properties

- **Droplet size:** internal-phase globules of 5–200 nm.
- **Low polydispersity index (PDI):** ≤ 0.3, indicating uniform droplets.
- **Rheology:** pseudoplastic (shear-thinning) behaviour — high viscosity at rest with lower viscosity during spreading.
- **Spreadability and extrudability:** easy, even spreading and simple extrusion from packaging.
- **Physical stability:** a thermodynamically stable dispersion resistant to creaming and phase separation.

Biological and dermatological compatibility

- **Skin-compatible pH:** stable within 5.0–7.0, ideally 5.5–6.5.
- **Non-irritant profile:** non-toxic, non-sensitising ingredients, with a preference for non-ionic surfactants such as Tween 80.
- **Targeted deposition:** inorganic filters remain on the stratum corneum, while hydrophilic antioxidants are delivered as nanodroplets to the viable epidermis and dermis.
- **Antioxidant activity:** strong DPPH and FRAP radical-scavenging performance.

Aesthetic and consumer appeal

- **Texture:** greaseless, non-sticky, refreshing hydrogel feel.
- **Washability:** easily removed with water without harsh cleansers.
- **Appearance and scent:** smooth, glossy, particle-free finish with a pleasant, mild scent [17,18].

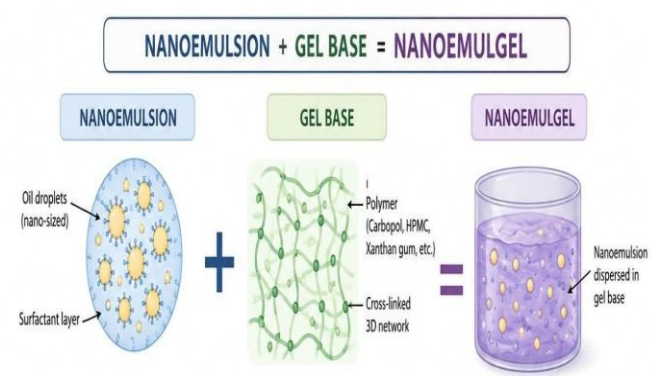

Figure 2. Schematic representation of nanoemulgel preparation by incorporation of the nanoemulsion into the gel base.

Benefits of Sunscreen Use

The primary purpose of sunscreen is to reflect, absorb or scatter harmful UV rays before they can damage viable skin tissue. Regular and appropriate application offers several well-documented benefits.

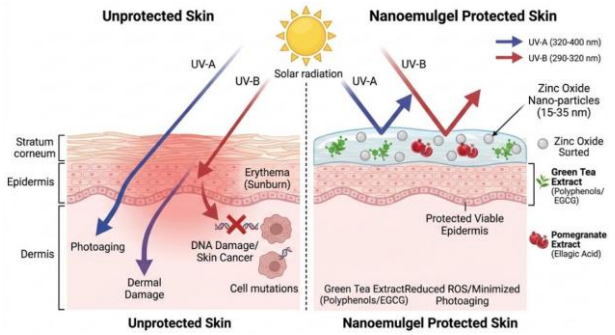

Figure 3. Comparative appearance of unprotected skin and skin protected with the nanoemulgel formulation.

- **Prevention of sunburn:** sunscreen significantly increases the skin's tolerance to UV exposure, delaying the onset of erythema (redness and inflammation) caused by UVB "burning" rays.
- **Reduced risk of skin cancer:** consistent use is associated with a decreased risk of developing actinic keratosis, squamous cell carcinoma and malignant melanoma. Sunscreens containing physical filters such as zinc oxide are particularly noted for their role in cancer prevention, as they block a primary cause of the disease.
- **Anti-aging and photoaging protection:** sunscreen is one of the most effective ways of preventing premature ageing. It protects the dermis from UVA rays, which otherwise cause loss of elasticity, sagging, and the formation of fine lines and wrinkles.
- **Maintenance of skin integrity:** by shielding the skin, sunscreens help maintain natural moisture levels and essential oils that would otherwise be depleted by sunlight. Ingredients such as glycerine and aloe vera, often added to formulations, further enhance hydration and skin-barrier recovery.
- **Biological and antioxidant defence:** modern formulations, especially those containing natural extracts such as green tea and pomegranate, provide secondary protection by neutralising reactive oxygen species and free radicals generated by UV exposure; these "UV boosters" also help protect DNA-repair enzymes from inactivation.
- **Prevention of discoloration:** regular application helps minimise skin darkening (tanning) and hyperpigmentation caused by the overproduction of melanin in response to UV radiation [1,4].

Aim and Objectives

The aim of this study was to develop and evaluate a herbal nanoemulgel containing green tea and pomegranate peel extracts for enhanced sunscreen and photoprotective activity. The specific objectives were to: (i) prepare and screen the two plant extracts; (ii) formulate a zinc-oxide-loaded nanoemulsion and incorporate it into a Carbopol gel base; and (iii) evaluate the resulting nanoemulgel for its physicochemical properties, drug-excipient compatibility and in-vitro SPF.

Materials and Methods

Plant material and extraction

Green tea leaves and pomegranate peels were collected, authenticated, shade-dried and coarsely powdered. Each powdered material (100 g) was macerated separately in 70% ethanol (~500 mL) in a stoppered vessel for 6 days at room temperature with intermittent shaking, after which the mixture was filtered through Whatman filter paper. The filtrates were concentrated on a water bath under controlled temperature and the concentrated extracts were stored in airtight containers until use [48].

Figure 4. Green tea leaves used for extract preparation.

Figure 5. Processed green tea used for extract preparation.

Table 1. Pharmacognostic profile of green tea (*Camellia sinensis).*

Common name	Green tea
Biological source	Dried leaves and leaf buds of *Camellia sinensis* (L.) Kuntze
Family	Theaceae
Main bioactive compounds	Rich in polyphenols, particularly epigallocatechin gallate (EGCG), epicatechin gallate (ECG), epigallocatechin (EGC) and epicatechin (EC).
Therapeutic role	Functions as a potent UV absorber, particularly in the UVB range, and acts as a free-radical scavenger. It helps prevent UV-induced photoaging and may provide protection against UV-related skin damage.
Safety	Clinical studies indicate that topical green tea preparations are generally well tolerated, with no significant allergenic or irritating effects reported [10].

Figure 6. Pomegranate peel used for extract preparation.

Figure 7. Powdered pomegranate peel used for extract preparation.

Table 2. Pharmacognostic profile of pomegranate (*Punica granatum*).

Common name	Pomegranate
Biological source	Dried rind/peel of the ripe fruit of *Punica granatum* L.
Family	Lythraceae
Main bioactive compounds	Highly enriched with ellagic acid, anthocyanidins and hydrolysable tannins.
Therapeutic role	Acts as a UV-protective enhancer and may help improve SPF. It suppresses collagen-decomposing enzymes (MMP-2 and MMP-13), supports skin moisturisation, and helps restore the skin barrier.
Safety	Obtained from agricultural waste, pomegranate peel is an eco-friendly and generally safe natural ingredient for topical applications [12,13].

Figure 8. Zinc oxide powder used as the inorganic UV filter.

Table 2. Zinc Oxid Powder

Category	Inorganic physical UV filter.
Therapeutic role	Provides broad-spectrum protection by reflecting, scattering and absorbing both UVA and UVB rays. It is a primary agent for preventing UV-induced carcinogenesis.
Properties	Generally appears as a white powder. When used as nanoparticles (15–35 nm), it maintains transparency on the skin, avoiding the “white cast” effect [42].

Formulation of the nanoemulgel

Table 3. Batch composition (per 100 g)

Ingredient	Quantity	Function
Green tea extract	10 mL	Active - UV booster/antioxidant
Pomegranate peel extract	10 mL	Active - UV booster/antioxidant

Zinc oxide	10 g	Inorganic UV filter
Carbopol 940	1 g	Gelling agent
Tween 80	3 g	Emulsifier
Liquid paraffin	6 g	Oil phase/emollient
Propylene glycol	5 g	Co-surfactant
Glycerine	5 g	Humectant
Methylparaben	0.2 g	Preservative
Triethanolamine	0.1 g	Neutraliser/pH adjuster

Preparation of green tea extract

Green tea extract was prepared by **maceration**. The materials required were green tea leaves, ethanol, double-distilled water, a mortar and pestle/grinder, a separating funnel with stopper, a beaker, a glass rod, cotton, filter paper and a water bath.

1. Green tea leaves were collected and authenticated.
2. The leaves were washed, shade-dried (where required), and coarsely powdered.
3. A known quantity of the powdered green tea (e.g., 100 g) was placed in a clean, dry, airtight separating funnel.
4. A suitable quantity of solvent (e.g., 70% ethanol, approximately 500 mL) was added so that the powder was completely immersed.
5. The funnel was tightly closed and kept for 6 days at room temperature.
6. The mixture was shaken occasionally to ensure proper contact between the powdered drug and the solvent.
7. After maceration, the mixture was filtered through Whatman filter paper.
8. The filtrate was concentrated using a water bath at a controlled temperature to obtain a concentrated green tea extract.
9. The concentrated extract was stored in an airtight container at a suitable temperature for further use [48].

Figure 9. Preparation of green tea extract by maceration.

Preparation of pomegranate peel extract

Pomegranate peel extract was likewise prepared by **maceration**, using dried pomegranate peels, ethanol, double-distilled water, a grinder, a separating funnel with stopper, filter paper, cotton, a glass rod and a water bath.

1. Fresh pomegranate fruits were collected and the peels were separated.
2. The peels were thoroughly washed to remove impurities.
3. The peels were shade-dried until completely free from moisture.
4. The dried peels were powdered using a mechanical grinder.
5. A known quantity of the powdered pomegranate peel (e.g., 100 g) was transferred into a clean, dry, airtight separating funnel.
6. About 500 mL of 70% ethanol was added to completely immerse the powdered material.
7. The mixture was kept for 6 days at room temperature with occasional stirring.
8. After maceration, the extract was filtered through Whatman filter paper.
9. The filtrate was concentrated using a water bath at controlled temperature to remove the solvent.
10. The concentrated extract was stored in an airtight container for further use [48].

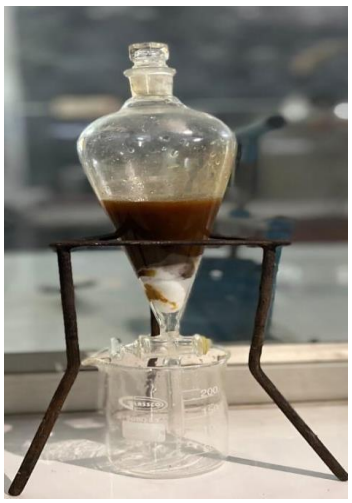

Figure 10. Preparation of pomegranate peel extract by maceration.

Preliminary phytochemical screening

Both extracts were screened by standard colour/precipitation tests: Mayer's test for alkaloids, the Shinoda (magnesium-HCl) test for flavonoids, the ferric chloride test for phenolics, the gelatin test for tannins, the froth test for saponins, and the Salkowski test for terpenoids [52].

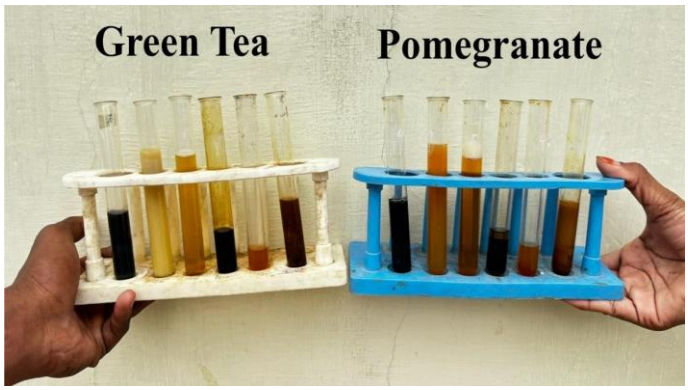

Figure 11. Preliminary phytochemical screening of the green tea and pomegranate peel extracts.

Preparation of the nanoemulgel

Carbopol 940 (1 g) was hydrated in ~40 g purified water for 30-60 min. Methylparaben was dissolved in propylene glycol with gentle heating and cooled. Liquid paraffin and Tween 80 were mixed and zinc oxide was dispersed into this oil phase. The two herbal extracts were combined in a small volume of water. The preservative solution, glycerine, herbal-extract solution and zinc-oxide dispersion were then added sequentially to the hydrated Carbopol gel with continuous stirring. Triethanolamine was added dropwise to neutralise the gel (target pH 6.0-7.0), and the batch weight was finally adjusted to 100 g with purified water. The gel was left to stand to remove entrapped air before being filled into airtight containers [49].

Figure 12. Hydration of the Carbopol 940 gel base.

Figure 13. Preparation of the combined herbal extract solution (green tea and pomegranate peel).

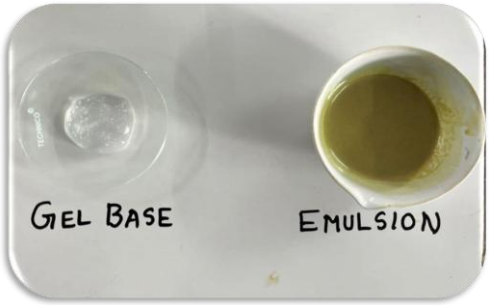

Figure 14. Gel base and the zinc-oxide oil-phase dispersion prior to combination.

Evaluation of the nanoemulgel

The finished formulation was assessed for appearance (colour, odour, texture, glossiness) by visual/organoleptic inspection [54]; pH, using a calibrated digital pH meter on a 1:10 aqueous dispersion [54]; viscosity, using a Brookfield viscometer (spindle 6, 30 rpm, 25 °C) and spreadability, by the parallel-plate (slip-and-drag) method, calculated as $S = (M \times L)/T$, where M is the applied weight, L the distance travelled and T the time taken.

Viscosity was determined using a rotational Brookfield viscometer fitted with a spindle selected according to the expected consistency of the preparation (Spindle No. 6 in the present study). A defined amount of the formulation (approximately 50 g in a 50 mL beaker, or 1 g placed directly on a plate) was prepared, and the spindle was lowered into the sample until the spindle groove reached the standardised depth. Measurements were taken at a controlled temperature, typically 25 °C, maintained using a thermostatic water bath, with the spindle rotated at a set speed — such as 20 or 25 rpm, or a series of progressive speeds (5, 10, 20, 30, 50 and 100 rpm) — to record the viscosity profile at different rotational stresses, after which the final viscosity value was calculated

Figure 15. pH determination of the formulated nanoemulgel using a calibrated digital pH meter.

Figure 16. Viscosity determination using a Brookfield viscometer.

Spreadability was assessed using the parallel-plate method, the most widely used and cost-effective technique for semisolid formulations. The apparatus consists of two glass slides of equal length: one is fixed to a stand, while the other is a movable slide attached to a pulley or hook.

Figure 17. Spreadability test setup using the parallel-plate (slip-and-drag) method.

In-vitro **SPF** was determined by the Mansur spectrophotometric method. A 1% w/v ethanolic stock of the formulation was diluted to a working concentration and its absorbance recorded from 290-320 nm at 5 nm intervals against an ethanol blank. SPF was calculated as $SPF = CF \times \Sigma[EE(\lambda) \times I(\lambda) \times Abs(\lambda)]$, where CF (=10) is the correction factor and $EE(\lambda) \times I(\lambda)$ are the standard normalised erythemal-effectiveness/solar-intensity constants of Sayre *et al*. Drug-excipient compatibility was assessed by FTIR spectroscopy of the physical mixture of formulation components.

Figure 18. Dilution of the nanoemulgel sample prior to spectrophotometric measurement for SPF determination.

Table 4. Standard normalised EE(λ) × I(λ) weighting constants used in the Mansur equation for in-vitro SPF calculation.

Wavelength (nm)	EE(λ) × I(λ) (normalised)
290	0.0150
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.0839
320	0.0180

Results and Discussion

The optimised nanoemulgel was a smooth, glossy, greenish-white semisolid with an agreeable herbal odour and a non-gritty, non-greasy, cream-like texture

Table 5. Physicochemical evaluation

Parameter	Result
Colour	Greenish-white
Odour	Agreeable, herbal
Texture	Smooth, non-gritty, non-greasy
pH	4.8
Viscosity (spindle 6, 30 rpm, 25 °C)	1993 cP
Spreadability	6.92 ± 0.18 cm

The measured pH (4.8) falls close to the physiological skin range and reflects adequate neutralisation of Carbopol 940 by triethanolamine, indicating good skin compatibility. The viscosity (1993 cP) is consistent with a well-structured Carbopol gel network and provided a consistency suited to topical application, while the spreadability value (6.92 ± 0.18 cm) indicates that the formulation spreads easily and uniformly on application.

In-vitro SPF

The summed weighted absorbance term $\Sigma[EE(\lambda) \times I(\lambda) \times Abs(\lambda)]$ was 3.0500, giving $SPF = 10 \times 3.0500 = 30.50$, which places the formulation in the SPF 30+ category. This performance reflects the combined contribution of zinc oxide (10% w/w) as the principal physical filter together with the polyphenol-rich green tea (1% w/w) and pomegranate peel (2% w/w) extracts, which are reported to provide additional UV attenuation and antioxidant support; Carbopol 940, Tween 80, glycerine, propylene glycol and liquid paraffin contributed to the physicochemical and topical-application properties of the base.

Table 6. Phytochemical screening

Test	*Green tea extract*	*Pomegranate peel extract*
Alkaloids	***Absent***	***Absent***
Flavonoids	***Present***	***Present***
Phenolics	***Present***	***Present***
Tannins	***Present***	***Present***
Saponins	***Present***	***Present***
Terpenoids	***Present***	***Present***

Both extracts were rich in flavonoids, phenolics, tannins, saponins and terpenoids, consistent with their reported antioxidant activity, while alkaloids were absent in both, in line with the known phytochemical profile of these plant materials.

Drug-excipient compatibility (FTIR)

FTIR analysis of the physical mixture of the formulation components showed no shift in the principal functional-group peaks (O-H, C-H, C-O and C-C stretching/bending) relative to the individual components, indicating the absence of any significant chemical interaction and confirming drug-excipient compatibility.

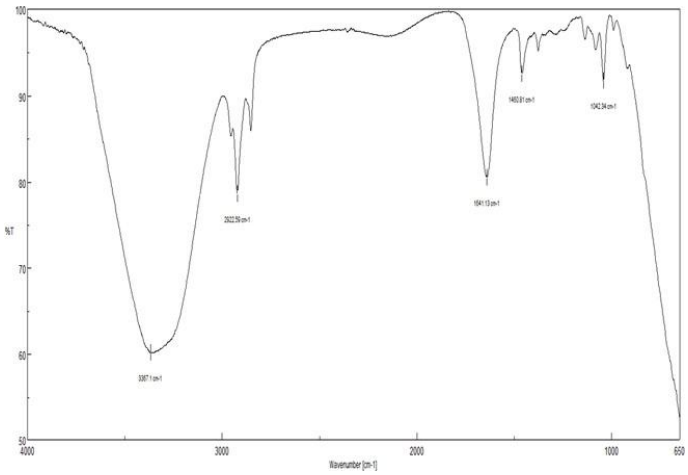

Figure 19. FTIR spectrum of the drug-excipient physical mixture of the nanoemulgel formulation.

Table 7. FTIR peak assignments for the drug-excipient physical mixture.

Functional group assigned	Peak value (cm^{-1})
O-H stretching	3367.10
C-H stretching	2955.40 / 2922.60 / 2853.20
C-H bending	1460.80 / 1377.90
C-O stretching	1082.80 / 1136.80
C-C stretching	1042.30

Conclusion

A herbal nanoemulgel combining zinc oxide with green tea and pomegranate peel extracts was successfully formulated and characterised. The optimised formulation showed satisfactory appearance, pH, viscosity and spreadability, an in-vitro SPF of 30.50 (SPF 30+ category), confirmed phytoconstituents, and good drug-excipient compatibility by FTIR. These findings support the formulation as a promising, cosmetically acceptable alternative to conventional sunscreens that merits further stability testing and in-vivo evaluation.

Acknowledgement

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