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Flower Extract-Reinforce ZnO Nanoparticles for Sustainable and Enhanced UV Protection

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Abstract—**The present study investigates the impact of natural flower extracts namely rose (*Rosa damascena*), sunflower (*Helianthus annuus*), zinnia (*Zinnia elegans*), kachnar (*Bauhinia variegata*), tuberose (*Polianthes tuberosa*), marigold (*Tagetes erecta*), and bougainvillea (*Bougainvillea spectabilis*) on Sun Protection Factor (SPF) when used in combination with zinc oxide (ZnO) nanoparticles. In this research ZnO nanoparticles were synthesized by sol-gel method. These particles were characterized through XRD, SEM, FTIR, UV and PL. The results confirm that ZnO nanoparticles were successfully synthesized which shows hexagonal wurtzite crystal structure. The extracts of flowers were obtained through ethanolic extraction. The obtained extracts were incorporated with ZnO nanoparticles in the matrix of prepared sunscreen for measurement of SPF. SPF was evaluated in vitro using spectrophotometry (Mansur equation). The results showed that the combination of sunflower and rose has higher SPF value because consists of higher carotenoids and flavonoids. After investigate all the results, this research suggest that integrating flower-derived bioactive compounds with ZnO nanoparticles offer a natural and effective strategy for developing broad-spectrum sunscreens with improved UV-blocking potential. The results validate flower extracts as eco-friendly, sustainable additives for boosting ZnO-based UV protection in cosmetics and textiles, reducing synthetic filter dependency. Further optimization of extract concentrations and stability is recommended for commercial applications.**

Index Terms—**Natural UV filters; ZnO nanoparticles; Floral extracts; SPF enhancement; Sustainable sun- screens.**

I. INTRODUCTION

Ultraviolet radiation reaches on the earth's surface from the sun. While it essential for the synthesis of vitamin D3 [1], but over exposure of UV radiation can cause for health risks, including immune system suppression, skin aging and an increased of skin cancer [1]. UV radiation is classified into three types based on wavelength: UVA(320-400nm), UVB(280-320nm) and UVC(100-280nm) [2], [3]. Both UVA and UVB penetrate the atmosphere and they have a strong biological and environmental effects and UVC is almost absorb by ozone layer of earth in atmosphere [4].

A. The essential for UV protection: biological Damage and health issue

The necessity of effective UV protection is underscored by the distinct and damaging mechanisms through which UVA and UVB radiation affect the skin at a biological damage. UVB radiation is a primary direct mutagen, absorbed by DNA to induce the formation of covalent linkages between adjacent pyrimidine bases. Cyclobutane pyrimidine dimers which is known as CPDs and (6-4) photo-product, these are the main two type of damage [5]–[7]. While CPDs are more abundant, comprising 70-80% of UV-induced lesions, 6-4PPs are considered more deleterious. They cause a more significant distortion of the DNA helix and are more mutagenic, frequently leading to T-to-C mutations if not repaired by the cell's nucleotide excision repair (NER) pathway [2], [6], [8]. Failure to fix DNA damage is an important cause of skin cancer such as basal cell and melanoma [1], [6]. In contrast, UVA radiation reaching on the dermal leyer which is most deeper layer of skin and damage the dermal layer directly. UV radiation is absorbed by molecules in skin which leads to the production of reactive oxygen species (ROS) which is unstable oxygen like hydrogen peroxide [9], [10]. High levels of ROS cause oxidative stress, which damages important cell components of skin like lipids, proteins, and DNA. One major damage is faster breakdown of the skin's extracellular matrix which means that, it breakdowns structural proteins like collagen and elastin, which stops to produce proteins in skin [11], [12] and then skin becomes start wrinkled , thin and weak. Therefore, complete photoprotection avoid both the direct DNA damage from UVB and the indirect damage caused by UVA induced ROS [13].

B. Current Challenges of UV Filters: Environmental and Health Concerns

For decades, sunscreens have responded on synthetic organic chemical filters like oxybenzone, octinoxate, and avobenzone for UV protection [14]. However, increasing evidence shows concern about their effect on the environment and human health, leading to a strong need for safer alternatives option. Environmentally, these chemicals are now recognized as significant pollutants. They enter aquatic ecosystems directly by washing off swimmers and indirectly through wastewater effluent [15], [16]. Studies have demonstrated that even at very low concentrations, oxybenzone and octinoxate can induce coral bleaching by promoting viral infections in their symbiotic algae (zooxanthellae), damage coral DNA, and cause de- velopmental deformities in coral larvae [17], [18]. Currently, concerns about human health have emerged. Many of these synthetic filters are absorbed through the skin and can be detected in blood, urine, and even breast milk [19], [20]. Chemicals such as oxybenzone, octinoxate, and homosalate are under scrutiny for potential endocrine-disrupting activities, meaning they can interfere with the body's natural hormone regulation, with potential links to reproductive and developmental issues [21]–[23]. Furthermore, allergic reactions and contact dermatitis are well- documented side effects for some individuals [24], [25]. These dual concerns have fueled a significant shift in consumer preference, leading to a rapidly growing market for sunscreens perceived as ”clean,” ”natural,” and ”reef-safe.”

C. Mineral- based Filter: Challenges Of Nano-ZnO

Because of health concern with synthetic UV filters this had led to increase interest in mineral based UV filters. Zinc Oxide(ZnO) and Titanium Oxide(TiO_2) are the most popular and common mineral which play important role to protect the skin from UVA and UVB rays [26]. Nanotechnology has made them much more effective in sunscreens. It has also improved their apperance, making them more appealing for cosmetic use. Traditionally, bulk ZnO nanoparticles are reflects visible light, which leaves white layer on the skin [27]. ZnO nanoparticles much smaller(size approx 100 nm) so they look transparent on skin while still effectively blocking UV rays [28], [29]. There are so many advantages of ZnO but there are also some challenges. A primary issue is aggreation is due to their high surface energy. When they clump , their effective surface area becomes smaller. This agglomeration leads to uneven protection and reduces their ability to block UV radiation [30], [31]. Another major concern is that ZnO photocatalytic active material. When it exposed to Uv light, Zinc Oxide produce ROS, Which may causes oxidative stress in skin cell. It is the same damage that sunscreen protect against [32]. Finally homogeneous and stable mixing of ZnO nanoparticles into cosmetics or textile is still major challenge [30]. These problem can be reduce by surface modification, where the Zno nanoparticles are mixed or coated with another materials to make them more stable and easy to make homogeneous mixture.

D. Sustainable Synergy: The Role of Natural Flower Extracts

This study proposes a new and eco-friendly approach to improve effectiveness of nano-ZnO combining it with natural flower extract. Flowers have bioactive component like flavonoids and carotenoids. These compounds are known for their strong antioxidant and UV absorbing properties [33]–[35]. These molecules have linked double bonds that help to protect skin from UV energy. Their phenolic structure compound help them to neutralize harmful free radicals. Because of this, they provide both UV protection and antioxidant benefits [35]. In this investigation, flower extracts were used from seven flowers which are: rose (*Rosa damascena*), sunflower (*Helianthus annuus*), zinnia (*Zinnia elegans*), kachnar (*Bauhinia variegata*), tuberose (*Polianthes tuberosa*), marigold (*Tagetes erecta*), and bougainvillea (*Bougainvillea spectabilis*). These flower were selected based on they contain many beneficial phytochemical. For example, sunflower has high carotenoids content such as lutein and zeaxanthin capable of effectively absorbing UVA radiation. Rose contains flavonoids like quercetin and kaempferol, whereas bougainvillea has been shown to possess flavonoids [35] and bet the overall main hypothesis of this study is that a combination of nano-ZnO with these flower extracts to increase effectiveness of the UV protection. This means that the extracts are supposed to neither would not only contribute to their own UV-absorbing capacity but also to “reinforce” ZnO nanoparticles. The organic molecule in flower extract act as natural capping agents for nanoparticles. These molecules attach themselves to the surface of the ZnO nanoparticles which form a protective layer that prevent them from clumping and help to maintain the nanoparticles as separate and well dispersed entities in the solution. This is not improves the stability of nanoparticles but also helps to enhance their effectiveness in various application. This dual-functionality directly addresses the primary drawbacks of nano-ZnO, more effective, and sustainable UV filter for use in cosmetics and textiles.

II. Methodology

A. Materials

Zinc acetate dihydrate $[Zn(CH_3COO)_2 \cdot 2H_2O]$, potassium hydroxide (KOH), methanol, and ethanol were of analytical grade. Flowers of rose (*Rosa damascena*), sunflower (*Helianthus annuus*), kachnar (*Bauhinia variegata*), zinnia (*Zinnia elegans*), tuberose (*Polianthes tuberosa*) and marigold (*Tagetes erecta*), bougainvillea (*Bougainvillea spectabilis*) were collected from local markets in Bhopal, India. Ingredients for lotion preparation, including almond oil, glycerin, beeswax, and coconut oil, were of cosmetic grade. All aqueous solutions were prepared using distilled water.

B. Synthesis of ZnO Nanoparticles via Sol-Gel Method

The sol-gel method was selected for the synthesis of ZnO nanoparticles due to its ability to produce a highly pure and homogeneous materials at low temperatures, with excellent control over particle size and morphology of the material. For synthesis of 7g of ZnO, 18.89g of zinc acetate dihydrate was added to methanol at room temperature to form a solution name A. Simultaneously, 8.792g of KOH was dissolved in Methanol to form a solution, named B. A small volume (100ml) of solution B was added dropwise to solution A under constant stirring until the initially undissolved zinc acetate fully dissolved. The remaining solution B was quickly added, leading to the formation of white gel with increased immediacy. The reaction mixture was stirred for a time estimated to be around 70 minutes, during which the gel transformed into a translucent material. This was followed by heating the solution to its boiling point for 25 minutes and leaving it overnight. There was the isolation of the white gel through centrifugation, washing with deionized water to eliminate impurities, followed by drying to obtain the final ZnO nanoparticles Powder. The process is shown in Fig.1 and the chemical reactions are involved in multiple steps. One of the steps is the dissolution of the zinc acetate in methanol. The addition of the strong base, KOH, provides hydroxide ions (OH^-), which react

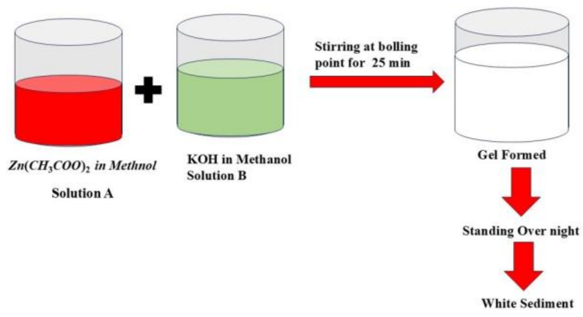

Fig. 1. Schematic diagram of the sol-gel process for ZnO nanoparticles

with the zinc ions (Zn^{2+}) to form a precipitate of hydroxide ($Zn(OH)_2$).

$$Zn^{2+}_{(sol)} + 2OH^{-}_{(sol)} \rightarrow Zn(OH)_{2(s)} \qquad (1)$$

Subsequent processes of heating and aging are pivotal in ensuring that the amorphous compound hydroxide changes to crystalline through dehydration:

$$Zn(OH)_{2(s)} \xrightarrow[Aging]{\Delta,} ZnO_{(s)} + H_2O_{(l)} \qquad (2)$$

Stirring for 70 minutes helps in the initial particle growth and refinement. Heating to boiling accelerates the dehydration reaction and enhances the crystallinity of the nanoparticles. Now the solution kept undisturbed for overnight. It helps the particles more uniform in size and crystal have better quality [36], [37].

C. Preparation Of Floral Extracts

The seven distinct flowers petals were carefully separated, washed, and dried in an oven at a controlled temperature of 40˚C. A low drying temperature is essential to remove moisture while minimizing the thermal degradation of heat-sensitive bioactive compounds like flavonoids and carotenoids. Form each flower was taken 5g of dried petals and added into 50ml of ethanol and stirred at 80˚C for 15 minutes [38]. The selection of ethanol as the extraction solvent plays a crucial role in the of the extraction process. Ethanol is a a moderately polar solvent, which allows it to dissolve organic compounds, includes both the polar compound such as flavonoids and as well as non-polar compound like carotenoids, ensuring the extraction of a broad range phytochemicals from the flower samples. using a elevated extraction temperature (80˚C) helps to improve the solubility of the target compounds in solvent allowing more phytochemical to dissolove. After extraction, the solutions were filtered using standard filter paper to remove solid petal debris. The resulting clear and pure flower extracts were stored in sealed glass bottles in a dark and cool place to prevent photodegradation and oxidation of the active compounds to preserving their potency for subsequent use.

D. Formulation of UV Protective Emulsion (Lotion)

A stable oil-in-water (O/W) emulsion base was prepared to serve as the vehicle for the sunscreen formulations. The formulation process involves the careful combination of an oil phase and an aqueous phase. Each and every ingredients has a important role to make the final product. In the oil phase, it contains 6g beeswax, 75ml coconut oil and 6ml almond oil. The aqueous phase contain 5g of glycerin and 100ml of distilled water, which both are dissolved very carefully. Both the aqueous and oil phase were separately in a water bath to a temperature between 80˚C to 100˚C. This heating step is essential to ensure that the beeswax is completely melted and uniformly dispersed in the oil phase and to bring both phases to a similar temperature helps prevent premature cooling or solidification when they are combined. After reaching the desired temperature, the hot aqueous phase was slowly added into the hot oil phase under a continuous string. The mixture was then subjected to high-shear mixing using a homogenizer. This mechanical process reduces the size of the dispersed oil droplets, creating a fine, homogeneous, and stable emulsion with a smooth, non-greasy texture to suitable for cosmetic the application. To prepare the sunscreen, ZnO nanoparticles were mixed into the base lotion with a 25% (w/w) ZnO concentration [39]. First 1.5g of ZnO nanoparticles powder was accurately weighed. Then it was added to 4.5g of the base lotion. The mixture was mixed thoroughly to spread the nanoparticles evenly. Uniform mixing is most important to ensure consistent UV protection. For formulations containing flower extracts, a 5% (w/w) concentration of the extract was added to the ZnO mixed lotion. For example, to prepare 100g of the final product, 5g of flower extract was added to 95g of the pre-homonized 25% ZnO lotion [40] and mixed to ensure uniform distribution. The final mixture was mixed again to evenly spread the flower extract throughout the emulsion. careful mixing is important when water-based extract which helps keep emulsion stable and prevent the separation of phases. For long-term storage and to prevent the growth of microbial, a suitable preservative system would be needed especially for commercial products.

III. Characterization Techniques

A suite of characterization techniques was used to analyze synthesized the material and confirm their properties, thereby confirming that: Determined the crystalline structure, crystallite size, and phase purity of the synthesized ZnO nanoparticles by the X-ray diffraction method. The diffractometer was used BRUKER D2 PHASER powder diffractometer with Cu Kα radiation (λ = 1.5406 Å , scanning from 2θ =30˚-70˚. Scanning Electron Microscopy SEM gave high-resolution images of the surface of synthesized material to visualize the morphology, size of the particles, and the distribution of shapes of the ZnO nanoparticles. Fourier Transform Infrared (FTIR) Spectroscopy gives the identification of the amount chemical functional groups present in a sample by measuring the absorbance of infrared radiation by the material. It was used to identify the Zn-O bond of the ZnO nanoparticles. UV-Visible spectroscopy measures ensures light absorption depending on the wavelength. It was used to confirm the formation of ZnO nanoparticles by identifying characteristic excitonic absorption peak, and calculate the optical band gap. Photoluminescence (PL) Spectroscopy, it measures the light emitted from a sample when material has excited by a light source. It provides information about the electronic structure and defect of the ZnO nanoparticles.

IV. Results and Discussion

A. XRD Analysis

The XRD pattern of the synthesized ZnO nanoparticles is shown in Fig.2. The pattern displays several sharp and well-defined diffraction peaks, indicating that the synthesized material is highly crystalline. The peaks observed at 2θ values of 31.98, 34.63, 36.46, 47.75, 56.81, 63.07, 66.63, 68.18 and 69.29 correspond to the (100), (002), (101), (102), (110), (103), (200), (112), and (201) crystallographic planes, respectively. All of these peaks are perfectly indexed to the hexagonal wurtzite structure of ZnO, in excellent agreement with the standard JCPDS card no. 36-1451. The absence of any other peaks confirms the phase purity of the synthesized ZnO. The crystallite size (D) of the nanoparticles was calculated

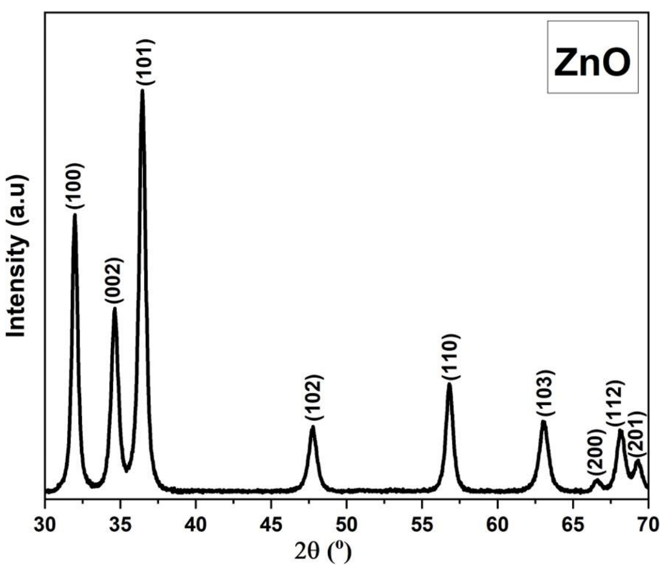

Fig. 2. XRD pattern of pure ZnO

from the broadening of the most intense diffraction peak using the Scherrer formula: (D) = $K\lambda\ /\beta \text{Cos}\theta$, where K is the Scherrer constant (0.94), λ is the X-ray wavelength (1.5406 Å), $\beta$is the full width at half maximum (FWHM) of the peak in radians, and θ is the Bragg angle [41]. The structural parameters derived from the XRD data are summarized in TABLE I. The calculated crystallite sizes are in the range of 12.39–16.45nm, confirming the synthesis of ZnO is in the nanoscale region. The average crystallite size is 14.23nm. Such small crystallite sizes imply a high surface-area-to-volume ratio, which is advantageous for enhancing UV interaction and catalytic activity. The calculated microstrain values are relatively low, suggesting a well-formed crystal lattice with minimal defects. The interplanar spacing (d) was calculated using Bragg's Law:

$$2d \sin \theta = n\lambda,$$

Here, λ is the wavelength of the ZnKα radiation radiation (1.54056 Å), d is the calculated interplanar spacing, θ is the scattering angle, and n is an integer representing the order of diffraction. A comparison between the observed and calculated interplanar spacing values of most dominant peak (101) is presented in TABLE II, further validates the crystalline structure.

TABLE I
XRD Peak Parameters, Crystallite Size, and Microstrain

Angle 2θ (°)	(hkl)	FWHM (β) (rad)	D (nm)	Microstrain ($\times 10^{-3}$)
31.98	(100)	0.5032	16.42	7.65
34.63	(002)	0.6425	12.95	8.99
36.46	(101)	0.5866	14.25	7.77
47.75	(102)	0.6920	12.55	6.82
56.81	(110)	0.6011	15.02	4.84
63.07	(103)	0.7517	12.39	5.34
66.07	(200)	0.5777	16.45	3.83
68.18	(112)	0.6850	14.00	4.41
69.29	(201)	0.6848	14.10	4.32

TABLE II
Comparison of observed and calculated interplanar spacing (d-values) for the dominant XRD peak.

Sample	**2θ (°)**	**d Observed (A°)**	**d calculated (A°)**
Pure ZnO	36.46	2.46	1.69

B. SEM Characterization of ZnO

The surface morphology, particle size, and distribution of the synthesized ZnO nanoparticles were characterized using Scanning Electron Microscopy (SEM). The images are shown in Fig.3 where it is evident that the obtained ZnO nanoparticles have a relatively homogeneous morphology. The particles are mostly spherical to near-spherical in nature, which is a typical form in wet chemical methods such as the sol-gel synthesis technique owing to the isotropic nature of the growth conditions. The approximate average particle size, as inferred from measurements done across the image, is found to be in the range of 200-300nm in size. This particular observation is relatable to the predefined crystallite size inferred from XRD measurements (average value is 14.23nm), with a slight variation often associated with the premise that the crystallite size obtained from XRD measurements corresponds to the coherent diffraction domains that can be smaller than the actual particle size observed by SEM if particles are poly-crystalline. There is a reasonably even spread of particles, showing that the process of synthesis (stirring, heating, and aging) was efficient in supporting controlled nucleation and growth. However, some level of agglomeration exists in some regions of the image. This agglomeration, where individual nanoparticles aggregate to form larger clusters is a typical problem encountered with

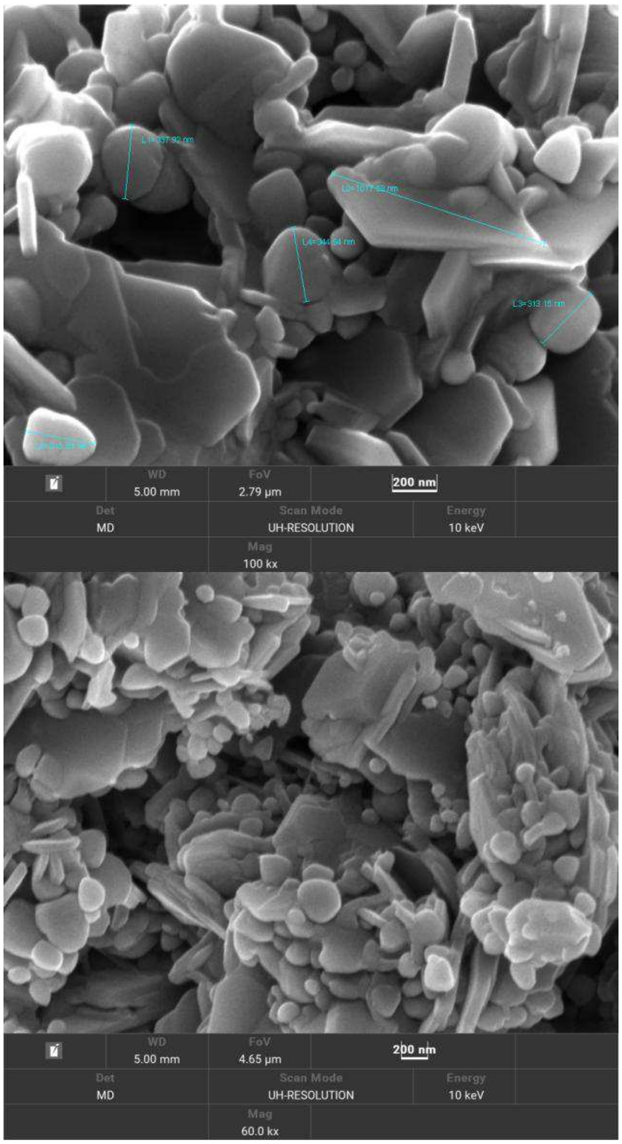

Fig. 3. SEM of ZnO

nanoparticles of high surface energy. The morphology and size distribution observed can be directly implications of UV protection efficiency and dispersibility the spherical shape of the ZnO nanoparticles. Spherical nanoparticles normally possess good scattering abilities against the UV part a broad spectrum. The size of the particles is small enough to ensure transparency in the visible spectrum, reducing the white cast color influence in cosmetic applications. Yet, the presence of agglomerates may negatively influence performance. Agglomerated particles effectively act as larger particles, thereby decreasing the UV protection efficiency, affect dispersibility and influence sensory properties. In sum, the SEM analysis shows the existence of the formation with nanoscale ZnO particles and a preferred spherical shape, and also underlining the importance of dispersion strategies, particularly in incorporating them into complex matrices.

C. FTIR Analysis

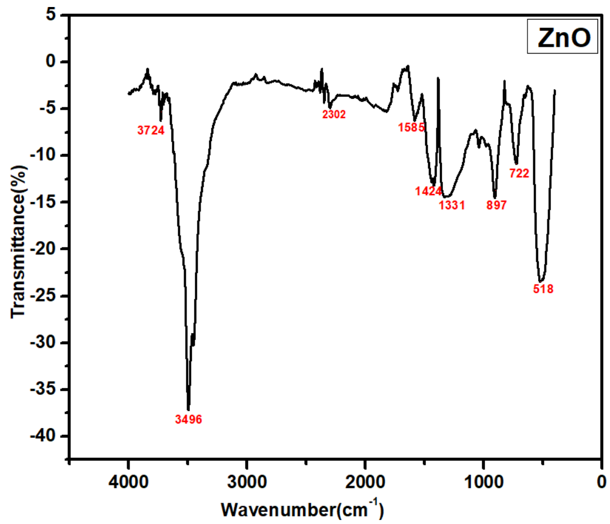

Fig. 4. FTIR of pure ZnO

Fourier Transform Infrared (FTIR) spectroscopy was employed to identify the functional groups present in the pure ZnO nanoparticles, thereby providing insights into potential interactions and successful surface modification. Fig.4 presents the FTIR spectra. The spectrum of pure ZnO typically shows a strong and broad absorption band in the low wavenumber region, around 400–500 cm^{-1}. This band is characteristic of the **Zn–O stretching vibration** in the wurtzite crystal lattice. Minor peaks may also be observed due to adsorbed atmospheric moisture, represented by a broad O–H stretching vibration around 3400 cm^{-1}, or due to atmospheric CO_2, appearing near 2350 cm^{-1}.

D. UV- Vis Analysis

The optical properties of the synthesized ZnO nanoparticles were studied using UV-Vis spectroscopy, with the resulting spectrum shown in Fig.5. The spectrum reveals a very strong and sharp absorption peak with an absorption edge at approximately 370nm. This is the characteristic excitonic absorption peak of ZnO, corresponding to the direct electron transition from the valence band to the conduction band. The optical band gap (E_g) was calculated using the formula $E_g = 1240/\lambda$, yielding a value of approximately 3.35 eV, which is in excellent agreement with the known band gap of bulk ZnO (3.37eV). Crucially, the spectrum shows very low absorbance in the visible region (400nm), confirming the material's transparency, which is a key requirement for its use in non-whitening sunscreens.

E. PL Analysis

In the given Fig.6, the spectrum shows the Photoluminescence (PL) analysis of Zinc Oxide (ZnO), which is a common tool for analyzing the optical and defective states in semiconducting materials. On the x-axis, "Wavelength (nm)" signifies

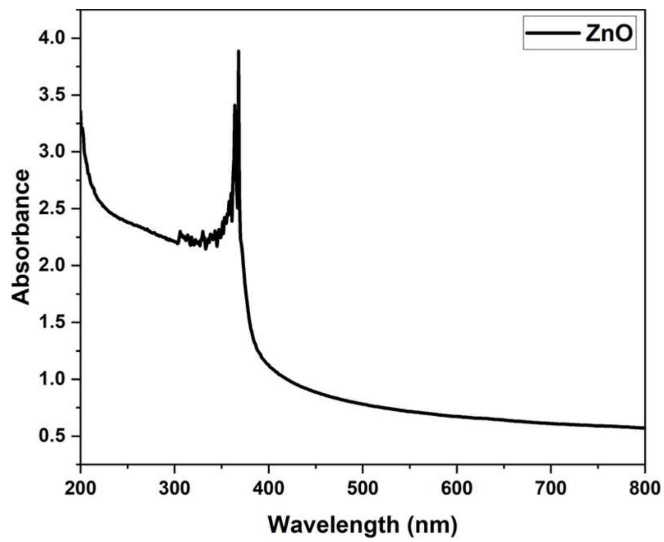

Fig. 5. UV of pure ZnO

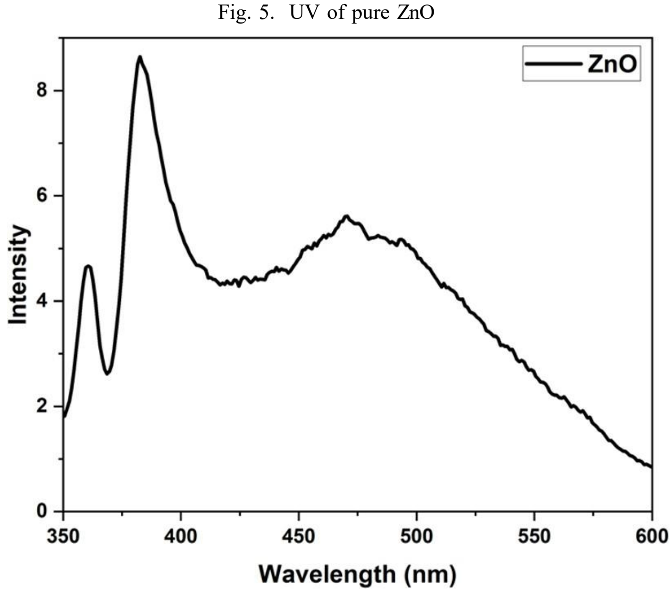

Fig. 6. PL of pure ZnO

the wavelengths of light emitted from the ZnO material when it is excited by an external source of light, generally in the ultraviolet region. On the y-axis, "PL Intensity(a.u.)" signifies the corresponding intensity or brightness of the light emitted at different wavelengths. A higher peak on the graph signifies higher brightness or higher intensity in those samples. In fig.6, the Photoluminescence analysis is shown. By analyzing the graph, it has been found that there is a dominant and sharp peak at about 375nm on the graph. This particular peak is an extremely dominant characteristic of the near-band-edge (NBE) emissions in ZnO. NBE emissions occur due to the recombination of excitons, which are basically electron-hole pairs, and are an exact manifestation of their inherent properties in the ZnO material. The presence of a strong NBE peak generally suggests good crystal quality and a low concentration of structural defects within the ZnO sample. While there's a smaller peak or shoulder preceding the main NBE peak, possibly indicating different excitonic recombination pathways, the dominant feature remains in the UV region. Notably, the spectrum does not show a prominent broad emission band in the visible light region (typically beyond 450nm and extending to longer wavelengths). The absence of strong visible emission, which is usually attributed to deep-level defects such as oxygen vacancies or zinc interstitials, suggests that the concentration of such defects in this particular ZnO sample is either low or that the measurement range did not extend sufficiently to capture them. Therefore, this PL spectrum primarily highlights the excellent optical quality of the ZnO material, characterized by its strong and efficient near-band-edge emission in the ultraviolet range.

F. Synergistic Enhancement of Sun Protection Factor in Sunscreen Formulations

The in-vitro SPF of the prepared sunscreen formulations was determined spectro photometrically using the Mansur equation [42]. Where

$$SPF_{spectrophotometric} = CF \times \sum_{290}^{320} \sum EE(\lambda) \times I(\lambda) \times Abs(\lambda)$$

TABLE III
NORMALIZED PRODUCT FUNCTION USED IN THE CALCULATION OF SPF

Wavelength (λ, nm)	EE × I (normalized)
290	0.0150
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.0839
320	0.0180
Total	**1**

EE – erythemal effect spectrum;
I – solar intensity spectrum

Here the CF is correction factor (10), was determined by Sayre et al.(1979) [42]and the value of $EE \times I$ is constant which is shown in TABLE III. TABLE IV shows the absorbance value of alone ZnO and each distinct flower extract with ZnO mixed lotion with five different wavelength gap (290,295,300,305,310,315,320) in between UVB region(290-300nm). The results, summarized in Fig.7 and TABLE V clearly demonstrate a powerful synergistic effect between the ZnO nanoparticles and the flower extracts. The base lotion without any active ingredients had a negligible SPF of 1.5. The formulation with 25% ZnO alone provided substantial protection with an SPF of 22.38. While the individual flower extracts showed modest SPF values on their own, their combination with ZnO led to a dramatic increase in protection. The most significant enhancements were observed with the extracts that showed the strongest UV absorption in the previous analysis. The formulation containing ZnO with sunflower extract and

TABLE IV
ABSORBANCE OF ZnO & COMBINATION OF ZnO WITH VARIOUS FLOWER EXTRACTS AT DIFFERENT WAVELENGTHS

Wave Length (nm)	EExI	Absorbance							
		ZnO	Sunflower	Rose	Marigold	Tube rose	Bougainvillea	Zinia	Kachner
290	0.0150	2.248	4.349	4.544	4.224	4.053	4.492	4.224	4.053
295	0.0817	2.233	4.134	3.467	3.867	3.867	4.028	3.867	3.867
300	0.2874	2.208	3.984	3.848	3.848	3.848	3.967	3.848	3.848
305	0.3278	2.256	4.033	3.904	3.904	3.904	3.979	3.904	3.904
310	0.1864	2.259	3.976	3.902	3.902	3.902	3.962	3.9023	3.899
315	0.0837	2.241	3.955	3.910	3.910	3.910	3.948	3.910	3.910
320	0.0180	2.184	3.946	3.919	3.919	3.919	3.940	3.919	3.927

TABLE V
SPF VALUE OF COMBINATION OF ZnO WITH VARIOUS FLOWER EXTRACTS

Sl. No	ZnO with Flower Extract	SPF Value
1	ZnO	22.38
2	Sunflower	40.146
3	Rose	40.146
4	Marigold	38.908
5	Tube rose	38.829
6	Bougainvillea	39.815
7	Zinia	38.908
8	Kachner	38.878

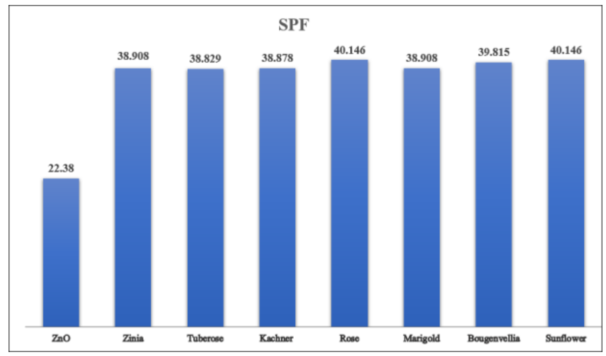

Fig. 7. ZnO mixed lotion with Flower Extract samples

combination of Zno with rose extract achieved an outstanding SPF of 40.146, which represents a 52.4% increase in protection compared to the ZnO-only formulation. Similarly, the combination with bougainvillea extract yielded an SPF of 39.815, a 42.8% increase.Other extracts equally contributed to the improvement, for example, the tube rose and kachner and marigold extract mixture increased the SPF to 38.878 and 38.908 (a 19.3% increase), although this improvement is more evident for sunflower and rose. Such a dramatic synergistic effect cannot be attributed to the additive principle. On the one hand, it has to do with the fact that the phytochemicals in the extracts absorb the UV light at different parts of the spectrum, complementing the ZnO absorbance profile. On the other hand, the organic molecules of the phytochemicals can bind to the ZnO nanoparticles to act as natural capping molecules. These molecules may provide steric hindrance to the ZnO nanoparticles to prevent aggregation. Hence, the observed aggregation in the bulk ZnO may be suppressed due to the steric hindrance. Ultimately, it is believed that due to the high antioxidant properties exhibited by the extracts, they are able to quench any ROS produced as a result of the photocatalytic effect of ZnO upon its exposure to UV radiation, making it safe to use. This is because, together, increased absorption, dispersion, and quenching are responsible for the synergistic enhancement of SPF.

V. CONCLUSION

This study successfully proves a highly effective synergistic approach that combines sol-gel synthesized ZnO nanoparticles (average crystalite size: 14.23nm) with natural flower extracts for improving UV protection. Some of its major conclusions and results confirm that sol-gel synthesized ZnO nanoparticles have phase-pure crystallinity and a hexagonal wurtzite structure with nanoscale dimensions. Data shows that the use of natural flower extracts enhances the SPF factors in commercial cosmetics significantly. More specifically, use of sunflower and rose extract demonstrated more than 52% improvement in SPF value to 40.146 compared to use of ZnO nanoparticles. Generally, its importance may be derived from its application towards facilitating effective and sustainable alternative development to existing commercially used UV filters. This is successfully achieved through the effective exploitation of its complementary UV absorption and strong antioxidant properties. Phytochemical constituents present in common flowers have been used in this process. These natural additives not only provide effective improvement in existing UV filter formulations and products. Additionally, they have good potential to overcome or mitigate existing nanoscale material properties such as aggregation and photo-catalysis associated with nanostructured ZnO. The present study forms a solid scientific basis for the development of a new generation of safe, eco-friendly, and highly effective UV-protective products for the cosmetic industry. In order to move this promising technology towards practical uses, some areas for future research that can help to accomplish this are identified below:

- Optimization and Stability: There should also be an investigation for optimizing the concentration ratio of ZnO and various flower extracts for maximum sunscreen and UVA protective factors. There is a need for comprehensive tests on stability, such as accelerated aging tests on lotions and wash durability tests on fabrics.

- Safety and Biocompatibility: In-vitro safety testing, such as cytotoxicity, skin irritation, and photosensitization studies, needs to be conducted on the final formulation to ascertain their compatibility and safety for use with consumers.
- Mechanistic Insight: The use of sophisticated surface analysis techniques (such as X-ray Photoelectron Spectroscopy analysis) and photoluminescence analysis would help to further understand the molecular interactions that are taking place between the ZnO surface and the extract, as well as the level of ROS suppression.
- Scalability and Formulation Science: Investigate scalable synthesis of the Composites and further formulation science are required for optimizing aesthetic and sensory properties, such as texturing, skin feel, color of the final product, if these products are to be viable within the market.

VI. CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Akshay Ruhidas: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft. **Vivek Chandel:** Data Curation, Formal Analysis, Visualization, Writing – Review and Editing. **Kajol Taiwade:** Data Curation, Writing – Review and Editing. **Madhulika Meena:** Data Curation, Methodology. **Dr. Fozia Zia Haque:** Conceptualization, Validation, Resources, Supervision. All authors have read and approved the final manuscript and authors agree to be fully accountable for the accuracy and integrity of the work.

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