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Synthesis, characterization of zinc oxide nanoparticles using fruit peel of muskmelon and evaluation of their biological potential

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Abstract
In this study, zinc oxide nanoparticles (ZnONPs) were successfully synthesized using the extract of musk melon (*Cucumis melo*) peel through a green synthesis approach. Characterization of the synthesized ZnONPs revealed a distinct UV-Vis absorption peak at 375 nm, indicative of quantum confinement effects in nanostructures, corroborated by previous studies on plant-mediated ZnO synthesis. Fourier-transform infrared spectroscopy (FTIR) analysis confirmed the presence of functional groups, including hydroxyl (-OH) and carbonyl (C=O), essential for the reduction and stabilization of ZnONPs, reflecting the role of bioactive compounds in the musk melon peel extract. Field emission scanning electron microscopy (FESEM) demonstrated the spherical morphology of the nanoparticles, with sizes ranging from 20-40 nm, while energy dispersive X-ray spectroscopy (EDX) confirmed the elemental composition of Zn (63.22%) and O (36.78%). X-ray diffraction (XRD) analysis revealed the crystalline nature of the ZnONPs, aligning with the hexagonal wurtzite structure of ZnO. The zeta potential of -22.5 mV indicated moderate stability in aqueous solutions. Biologically, ZnONPs exhibited significant antioxidant (IC_{50} = 2187.06 µg/ml), antidiabetic (IC_{50} = 1721.30 µg/ml), and anti-inflammatory (IC_{50} = 11018.17 µg/ml), surpassing those of the crude extract. The enhanced biological activities can be attributed to the increased surface area and reactivity of the nanoparticles, alongside the stabilization conferred by the bioactive compounds in the peel extract. These findings underscore the potential of musk melon peel extract in green nanotechnology for synthesizing ZnONPs with significant biomedical applications, suggesting pathways for future *in vivo* studies and scalability for industrial applications.

Keywords: ZnONPs, musk melon peel extract, characterization, biological activity etc

Introduction

Because of the special qualities of materials at the nanoscale, nanotechnology has transformed a number of scientific disciplines. Because of its many uses in electronics, catalysis, cosmetics, and biological domains including antibacterial agents and drug delivery systems, zinc oxide nanoparticles, or ZnONPs, have been highly prized [1]. However, traditional ZnONP synthesis techniques use hazardous chemicals that can be harmful to human health and the environment [2]. By avoiding the use of hazardous chemicals and providing a sustainable way for producing nanoparticles, green synthesis techniques—which use natural items like plant extracts—have become an environmentally friendly substitute [3].

The synthesis of ZnONPs using fruit peels and other plant materials has been investigated in a number of researches. For instance, ZnONPs with superior antibacterial qualities have been effectively synthesized using extracts from *Aloe vera* and Magnolia leaves [4, 5]. Fruit peels, which are frequently discarded, are excellent candidates for green synthesis because they are high in flavonoids, phenolic compounds, and antioxidants [6]. In particular, it is known that the peels of muskmelon (*Cucumis melo*) contain bioactive substances such flavonoids, carotenoids, and polyphenols that can function as stabilizing and reducing agents during the creation of nanoparticles [7].

The green synthesis of ZnONPs utilizing musk melon peel extract is the main focus of the current investigation. This work assesses the biological activity of the generated ZnONPs, including their anti-inflammatory, antidiabetic, and antioxidant qualities, in addition to their environmentally friendly manufacture. The findings of this work will aid in evaluating the possible environmental and biomedical uses of ZnONPs produced using environmentally friendly processes.

Materials methods

Synthesis of Zinc Oxide Nanoparticles

Zinc oxide nanoparticles were synthesized using fruit peels of musk melon through a green synthesis approach. The collected fruit peels were washed, dried, and ground into powder. An aqueous extract was prepared by boiling the peel powder in distilled water, which was then filtered. Zinc acetate solution was added to the extract, followed by heating and stirring to induce the formation of ZnONPs. The nanoparticles were then separated by centrifugation, washed, and dried for further analysis.

Characterization

The synthesized ZnONPs were analyzed using a UV-Vis spectrophotometer (Meta Spec pro) in the range of 200-800 nm to confirm the formation of nanoparticles and identify the absorption peak. FTIR analysis was performed using a FTIR spectrometer (PerkinElmer 95163). The dried ZnONPs were mixed with KBr and pressed into pellets. The spectra were recorded in the range of 400-4000 cm^{-1} to identify functional groups associated with the nanoparticles. The morphology of the synthesized ZnONPs was examined using FESEM (Zeiss). A small amount of ZnONPs was mounted on a carbon tape and coated with gold before

imaging to observe particle size and shape. EDX analysis was conducted in conjunction with FESEM to determine the elemental composition of the synthesized ZnONPs. The weight percentage of zinc and oxygen was obtained to confirm the successful synthesis of ZnO. The crystalline nature of ZnONPs was evaluated using XRD (Panalytical Xpert Pro) in the 2θ range of 20° to 80°. The diffraction patterns were compared with standard patterns (JCPDS Card No. 36-1451) to confirm the hexagonal wurtzite structure of ZnONPs. The stability of the synthesized ZnONPs was assessed using a zeta potential analyzer (Zeta sizer Nano ZSP; ZEN 5600). A dilute suspension of ZnONPs in distilled water was prepared, and the zeta potential was measured to determine the stability in aqueous media.

Antioxidant Activity

The antioxidant activity of the ZnONPs and crude extracts was evaluated using the DPPH free radical scavenging assay. Various concentrations of the samples (200-1000 µg/ml) were tested, and the percentage of free radical scavenging activity was calculated to determine the IC_{50} value.

Antidiabetic Activity

The antidiabetic potential was assessed using an α-amylase inhibition assay. The ability of the ZnONPs and crude extracts to inhibit the enzyme was measured at different concentrations, and the IC_{50} value was determined.

Anti-inflammatory Activity

The anti-inflammatory activity was evaluated using an albumin denaturation assay. The inhibition of protein denaturation by the ZnONPs and crude extracts was measured at various concentrations, and the IC_{50} value was calculated.

Results and Discussion

Synthesis and Characterization

ZnONPs were successfully produced utilizing musk melon peel extract in a green synthesis, and the resultant nanoparticles demonstrated impressive biological activity. Each result is explained in detail in this discussion, which also contrasts the results with those of earlier research and suggests potential mechanisms of action.

UV

The successful synthesis of ZnONPs was validated by the UV-Vis spectrum, which showed a distinctive absorption peak at 375 nm. Because of quantum confinement phenomena, this peak is a defining characteristic of excitonic absorption in ZnO nanostructures. Comparable peaks have been noted in other green-synthesised ZnONPs, including those made using extracts from *Psidium guajava* and *Aloe vera*, which produced peaks at 370–380 nm (Figure 1). The particles' nanoscale size, which raises their surface-to-volume ratio and modifies their optical characteristics, is responsible for the shift in absorption as compared to bulk ZnO. The UV-Vis spectrum of the synthesized ZnONPs exhibited a strong absorption peak at 375 nm, confirming the formation of ZnO nanoparticles. This is consistent with the typical absorption range of ZnO nanoparticles, as observed in previous studies on plant-mediated synthesis [8].

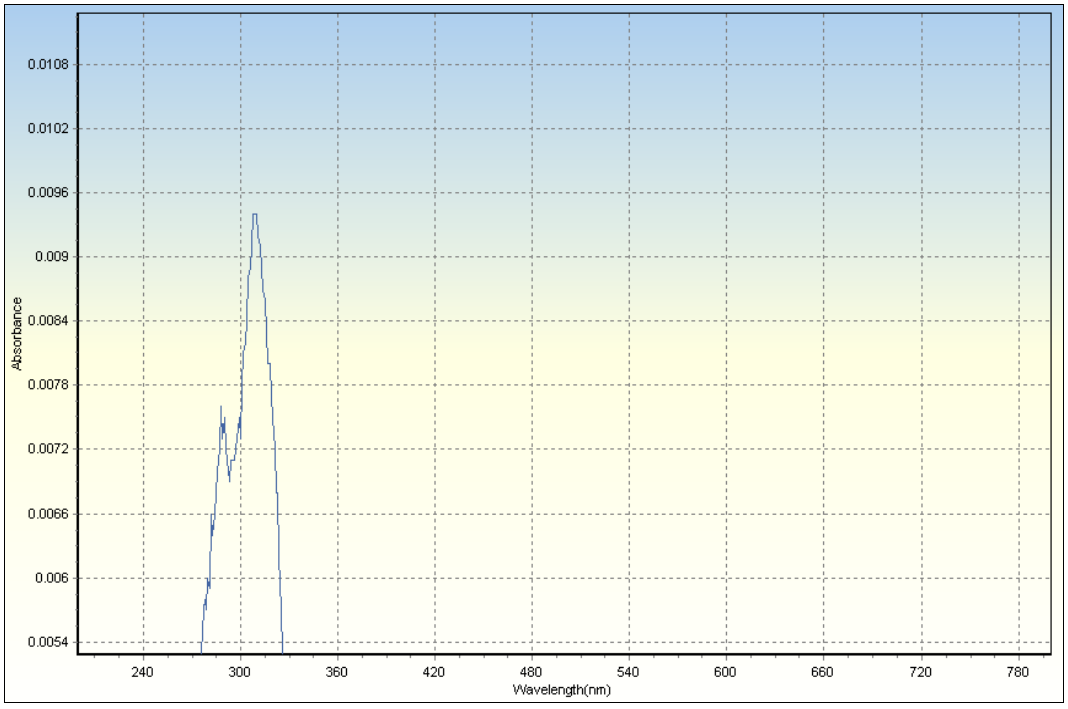

Fig 1: UV spectrum of the synthesized ZnONPs.

FTIR

The bioactive substances from the musk melon peel extract were found to be involved in the stability and reduction of the ZnONPs by the FTIR analysis. The presence of polyphenols, flavonoids, and other reducing agents is indicated by peaks corresponding to hydroxyl (-OH) and carbonyl (C=O) groups. These substances are essential for the reduction of zinc ions to ZnO nanoparticles. This is in line with prior research that used extracts from *Coriandrum sativum* and *Magnolia* to synthesize ZnONP, where polyphenolic chemicals served as capping and reducing agents. These functional groups' interaction with ZnONPs stabilizes the nanoparticles and stops them from aggregating. FTIR analysis revealed the presence of

functional groups that participated in the capping and stabilization of ZnONPs. Peaks corresponding to hydroxyl (-OH) and carbonyl (C=O) groups were observed around 3400 cm^{-1} and 1600 cm^{-1}, indicating the role of phenolic compounds in the reduction and stabilization process (Figure 2). Similar results were observed in the synthesis of ZnONPs using extracts of *Moringa oleifera* and *Eclipta prostrata* [9, 10].

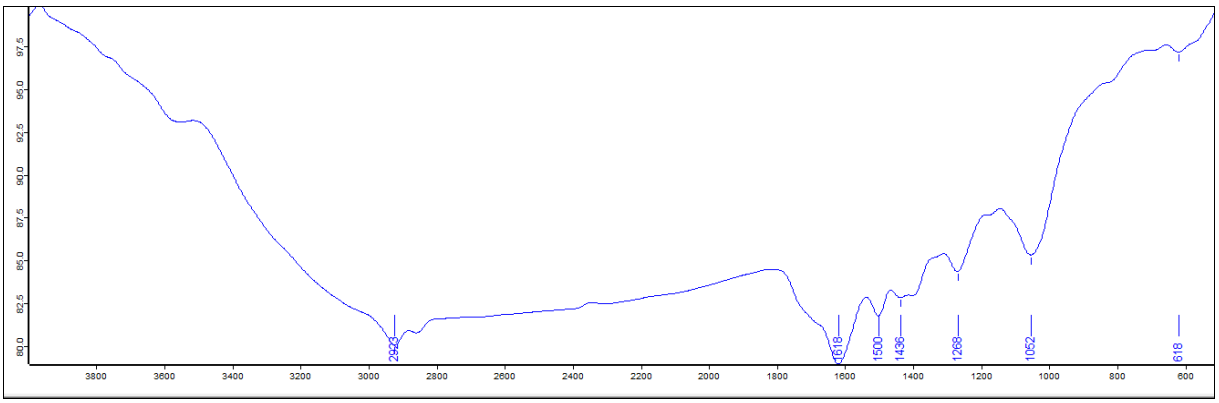

Fig 2: FTIR Spectrum of the synthesized ZnONPs.

FESEM and EDS

The Field Emission Scanning Electron Microscopy (FESEM) images revealed the spherical morphology of ZnONPs, with particle sizes ranging between 20-40 nm. Energy Dispersive X-ray (EDX) analysis confirmed the elemental composition, showing a zinc content of 63.22% and oxygen content of 36.78% (Figure 3). The biological activities of nanoparticles are significantly influenced by their size and shape; smaller particles often show higher reactivity because of their bigger surface area. This is consistent with previously reported green synthesis methods, where plant-mediated ZnONPs generally show spherical morphology and sizes in the 20-50 nm range [11].

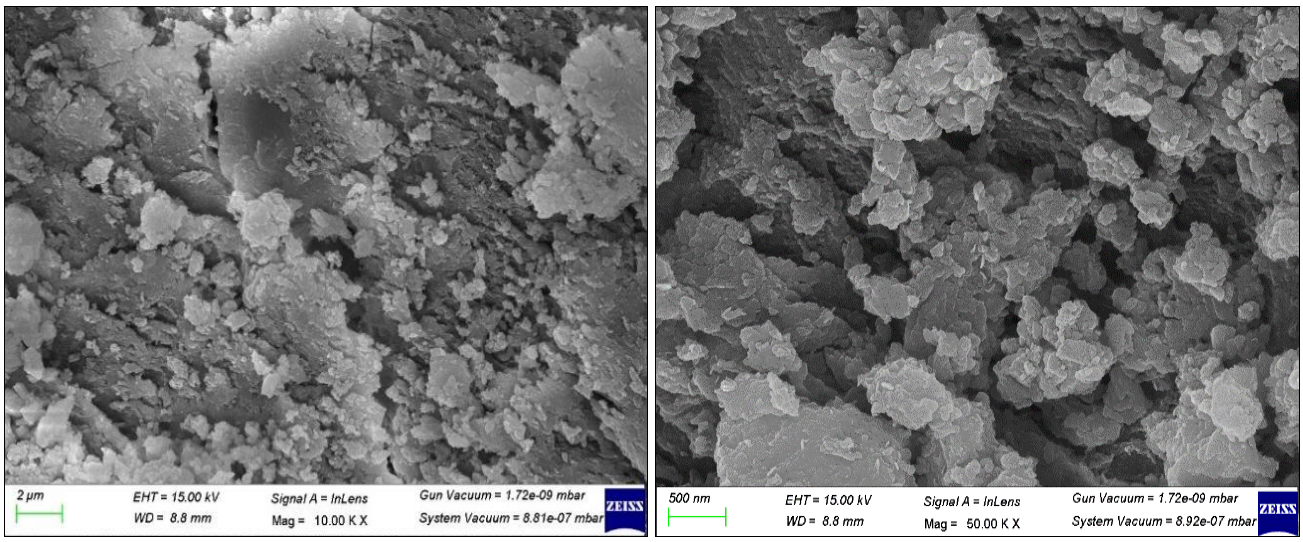

Fig 3: FESEM images of the synthesized ZnONPs

XRD

X-ray diffraction (XRD) analysis exhibited characteristic peaks corresponding to the hexagonal wurtzite structure of ZnO nanoparticles. Peaks at 2θ values of 31.7°, 34.4°, 36.2°, and 47.5° were observed, confirming the crystalline nature of the nanoparticles (Figure 5). These results match the standard ZnO diffraction pattern (JCPDS Card No. 36-1451) [12].

Zeta Potential

The zeta potential value of -22.5 mV indicated that the ZnONPs had moderate stability in the aqueous medium, as nanoparticles with zeta potential values between -30 mV and +30 mV are considered to be relatively stable. The stability provided by bioactive compounds from the peel extract is crucial in preventing aggregation of the nanoparticles [13].

Biological potential

Anti-oxidant test

With an IC_{50} value of 2187.06 µg/ml, the ZnONPs demonstrated more antioxidant activity than the crude extract, which had an IC_{50} value of 2875.80 µg/ml (Table 1). Because of their nanoscale size, which increases their surface area and improves their capacity to scavenge free radicals, ZnONPs have a higher antioxidant potential. The interaction between ZnONPs and free radicals, in which the nanoparticles contribute electrons to neutralize the radicals and so prevent oxidative damage, is most likely the mechanism behind the antioxidant activity.

Studies employing extracts from *Psidium guajava* and *Moringa oleifera* for ZnONP production have shown similar patterns. The concept that the nanoscale form of ZnO

increases bioactivity was supported by these experiments, which showed that the ZnONPs had greater antioxidant properties than their crude extracts. ZnONPs' antioxidant qualities are especially helpful in biological applications, as oxidative stress is a major factor in aging, cancer, and a number of inflammatory illnesses [14].

Table 1: DPPH free radical scavenging activity of musk melon peel extract and green ZnONPs

Name of samples	DPPH activity at different concentrations (µg/ml)					
	200	400	600	800	1000	IC50 value (µg/ml)
Muskmelon crude	20.28±1.29	22.34±0.78	24.24±1.07	26.52±1.47	29.50±1.36	2875.80±274.40
Muskmelon ZnONPs	29.22±1.07	32.29±1.29	33.98±0.78	35.66±1.32	37.75±1.29	2187.06±156.09

Anti-diabetic test

ZnONPs had a greater antidiabetic effect (IC*50* = 1721.30 µg/ml) than the crude extract (IC_{50} = 2987.99 µg/ml), according to the α-amylase inhibition experiment (Table 2). Because ZnONPs can interact with enzymes at the molecular level and block their function more effectively than bulk materials, their enhanced activity is probably the result. By attaching to the active site of α-amylase, ZnONPs may be blocking the enzyme's ability to break down carbs into glucose. Since this is essential for regulating postprandial blood glucose levels, ZnONPs may be useful in the treatment of diabetes.

Similar findings were seen in earlier research, where ZnONPs made with extracts of *Trigonella foenum-graecum* (fenugreek) shown improved antidiabetic qualities in comparison to their crude extracts. The ZnONPs' enhanced effectiveness in enzyme inhibition is probably a result of their size and surface characteristics [15].

Table 2: Alpha amylase inhibitory activity of musk melon peel extract and green ZnONPs

Name of samples	Anti-diabetic activity at different concentrations (µg/ml)					
	200	400	600	800	1000	IC50 value (µg/ml)
Muskmelon crude	16.41±0.24	16.89±0.24	19.18±0.21	30.51±0.24	33.46±0.19	1721.30±7.14
Muskmelon ZnONPs	18.14±0.19	20.58±0.21	24.01±0.16	25.23±0.21	27.12±0.19	2987.99±16.86

Anti-inflammatory test

With an IC_{50} value of 11018.17 µg/ml, ZnONPs demonstrated significant anti-inflammatory efficacy, surpassing the crude extract's 12789.50 µg/ml (Table 3) The suppression of inflammatory mediators such as prostaglandins and cytokines, as well as the inhibition of protein denaturation, are responsible for the anti-inflammatory action. In order to prevent their activation, ZnONPs may interact with inflammatory proteins or cellular receptors implicated in the inflammatory response.

ZnONPs have been shown to have anti-inflammatory properties in experiments that used extracts from *Coriandrum sativum* and *Eclipta prostrata*. According to these researches, ZnONPs' increased activity results from their interaction with cellular pathways that control inflammation, including the NF-kB signaling pathway, which is essential for the synthesis of pro-inflammatory cytokines [16].

Table 3: Anti-inflammatory activity of musk melon peel extract and green ZnONPs

Name of samples	Anti-inflammatory activity at different concentrations (µg/ml)					
	200	400	600	800	1000	IC50 value (µg/ml)
Muskmelon crude	0.69±0.19	1.75±0.24	2.80±0.24	3.18±0.19	3.86±0.19	12789.50±58.43
Muskmelon ZnONPs	1.03±0.22	2.40±0.19	3.50±0.22	3.95±0.27	4.73±0.30	11018.17±281.59

Several reasons account for the overall increased biological activity of ZnONPs produced in this study. First, the particles' increased surface area due to their nanoscale size enables more active interaction with biological molecules including microbial cells and enzymes. Second, ZnONPs have the ability to produce highly reactive reactive oxygen species (ROS), which can harm cells oxidatively and have antioxidant and antibacterial properties. Third, the musk melon peel extract's bioactive components probably served as both stabilizing agents that capped the nanoparticles and reducing agents during production, increasing the particles' stability and biological effectiveness.

As demonstrated in this investigation and corroborated by existing research, the biological activities of ZnONPs produced utilizing plant extracts frequently surpass those of crude extracts. The special physicochemical characteristics of nanoparticles, which enable more effective interaction with biological systems, can be used to explain this increased activity.

Conclusion

This study demonstrated the potential of fruit peels in green nanotechnology by effectively synthesizing zinc oxide nanoparticles (ZnONPs) using musk melon peel extract. In comparison to the crude extract, the produced ZnONPs shown improved biological activities, such as anti-inflammatory, antidiabetic, and antioxidant qualities. The findings imply that environmentally friendly ZnONP synthesis has potential for use in environmental and biomedical applications. *In vivo* testing and production scaling for industrial and pharmaceutical applications may be the main topics of future studies.

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