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Synthesis of zinc oxide nanoparticles using fruit peels of Muskmelon and their biological potential

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Abstract
The growing concern of antibiotic resistance and the need for sustainable medicines have fuelled interest in plant-based nanotechnology. In this research, green synthesis of zinc oxide nanoparticles (ZnONPs) from kitchen waste in the form of bitter gourd (*Momordica charantia*) fruit peels was investigated as a sustainable, eco-friendly, and cost-effective approach compared to traditional processes. The ZnONPs synthesized were tested for antioxidant, antidiabetic, anti-inflammatory, and antimicrobial properties and compared with crude plant extracts. The ZnONPs exhibited much improved bioactivity, with more powerful free radical scavenging (IC_{50} = 384.10 µg/ml), α-amylase inhibitory (IC_{50} = 1114.77 µg/ml), and anti-inflammatory activities (IC_{50} = 10395.18 µg/ml) than crude extracts. The enhanced bioefficacy is due to the surface area and reactivity of nanoparticles and synergistic effects of bioactive compounds in bitter gourd peels. This research is revealing a double advantage: the valorization of kitchen waste and the promotion of sustainable nanotherapeutics. The discovery proposes ZnONPs prepared from fruit peels as potential agents for fighting oxidative stress, diabetes, and microbial infections and promoting green nanomedicine development.

Keywords: Antibiotic resistance, green synthesis, zinc oxide nanoparticles, bitter gourd peels

Introduction
The growing incidence of antibiotic-resistant bacteria has accelerated the search for novel therapeutic options, and hence the interest in using natural products and nanotechnology has gained momentum. Since ancient times, medicinal plants have been a treasure trove of bioactive natural compounds (Mc Neil, 2005). Recent advances in green nanotechnology have provided new opportunities for augmenting the potency of these natural molecules. From the plants considered, bitter gourd (*Momordica charantia*) has been well-documented for its medicinal use, especially in the control of diabetes, inflammation, and microbicidal infections (Jia *et al.*, 2017) [2].

Here, we emphasize the creative application of kitchen waste in the form of bitter gourd fruit peels as an eco-friendly and sustainable material for the synthesis of ZnONPs. Fruit peels utilization not only increases the value of waste material but also supports the international drive for reducing waste and promoting a green environment. The production of ZnONPs through plant extracts, especially those from waste products, is a green chemistry strategy that is both environmentally conscious and involves the creation of highly effective therapeutic agents (Pathak *et al.*, 2017) [5].

This study seeks to determine the bioactivity of ZnONPs prepared from bitter gourd fruit peels and compare their potency with that of crude extracts. The research analyzes the antioxidant, antidiabetic, anti-inflammatory, and antimicrobial activity of the ZnONPs and investigates their prospects as a promising alternative to traditional treatments. Using kitchen waste, this study also adds to the developing trend in sustainable nanotechnology.

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.

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 IC50 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 IC50 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
Antioxidant Activity
ZnONPs prepared from bitter gourd fruit peels exhibited considerably higher antioxidant activity than that of the crude extract. The ZnONPs indicated 71.57% free radical scavenging activity at a concentration of 1000 µg/ml with an IC_{50} value of 384.10 µg/ml, whereas the crude extract evidenced only 10% activity with an IC_{50} value of 7958.11 µg/ml.

Table 1: DPPH Free radical scavenging assay of the extract and the synthesized nanoparticles.

Name of samples	% Free radical scavenging activity at different concentrations (µg/ml)					
	200	400	600	800	1000	IC_{50} value (µg/ml)
Bittergurad extract	4.80±0.23	5.86±0.24	6.34±0.23	7.16±0.26	10.00±0.26	7958.11±101.98
Bitterguard ZnONPs	38.97±4.80	52.43±0.52	63.39±0.16	66.22±0.23	71.57±0.26	384.10±10.40

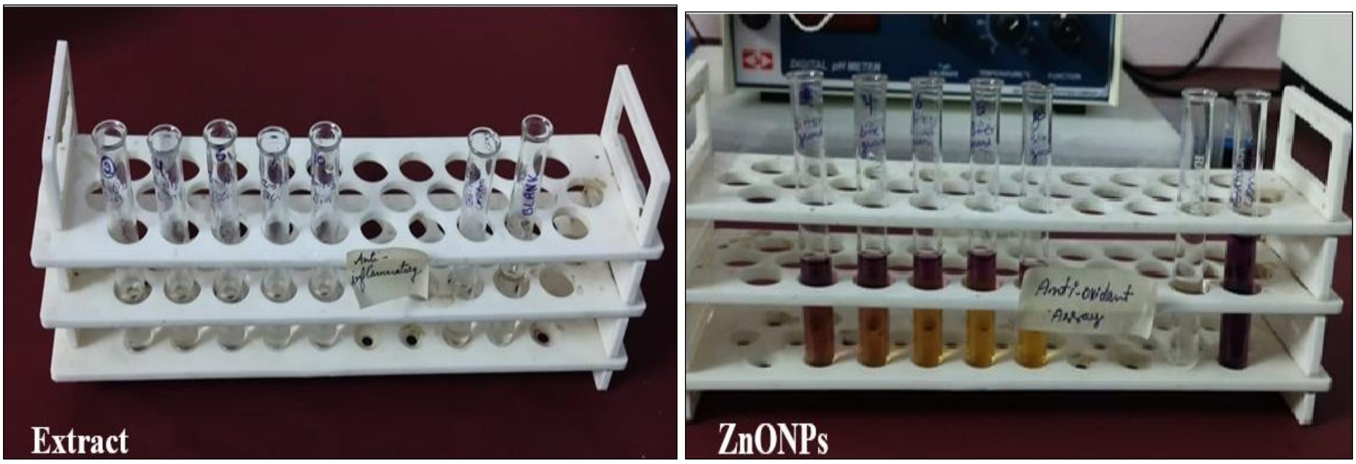

Fig 1: Photographs of antioxidant assay.

Antidiabetic Activity

The ZnONPs had greater antidiabetic potential compared to the crude extract. ZnONPs had 49.71% of maximum ctivity at 1000 µg/ml, with an IC_{50} value of 1114.77 µg/ml, whereas the maximum activity was observed in the crude extract as 38.16% and had an IC50 value of 2771.27 µg/ml.

Table 2: Anti-diabetic activity of the extract and the synthesized nanoparticles.

Name of samples	Anti-diabetic activity at different concentrations (µg/ml)					
	200	400	600	800	1000	IC50 value (µg/ml)
Bittergurad extract	32.55±1.08	33.92±40.53	36.08±0.24	37.55±1.10	38.16±1.21	2771.27±86.35
Bitterguard ZnONPs	35.78±0.30	40.53±3.86	41.85±4.48	45.69±4.81	49.71±4.48	1114.77±38.75

Fig 2: Photographs of antidiabetic assay.

Anti-inflammatory Activity

ZnONPs prepared from bitter gourd fruit peels also showed increased anti-inflammatory activity with a maximum inhibition of 6.66% at 1000 µg/ml and an IC_{50} value of 10395.18 µg/ml, in comparison with the crude extract, which has a maximum inhibition of 4.97% and an IC50 value of 10962.58 µg/ml.

Table 3: Anti-inflammatory activity of the extract and the synthesized nanoparticles.

Name of samples	Anti-inflammatory activity at different concentrations (µg/ml)					
	200	**400**	**600**	**800**	**1000**	**IC_{50} value (µg/ml)**
Bittergurad extract	1.47±0.23	1.97±0.18	2.67±0.26	4.04±0.18	4.97±0.18	10962.58±9.84
Bitterguard ZnONPs	2.09±0.18	2.21±0.26	4.18±0.18	4.83±0.15	6.66±1.87	10395.18±15.51

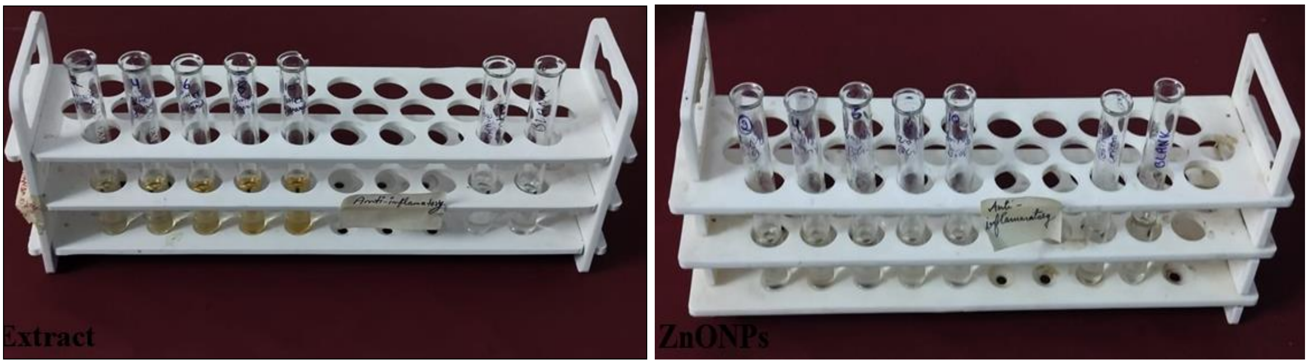

Fig 3: Photograph of anti-inflammatory activity.

Discussion

The results of this research emphasize the promising bioactivity of ZnONPs prepared from bitter gourd fruit peels, proving to be of greater efficacy compared to crude extracts. The utilization of kitchen waste, like fruit peels, as a raw material for nanoparticle preparation is especially significant as it induces environmental sustainability along with the development of useful therapeutic agents.

The utilization of fruit peels, a waste product of domestic food processing, is a sustainable method of synthesizing nanomaterials. Besides minimizing waste, this technique offers an inexpensive source of bioactive molecules that can be used for the green synthesis of ZnONPs. Repurposing waste materials, this research supports the circular economy and the global initiative to reduce environmental footprints (Verma *et al.*, 2021) [6].

The enhanced antioxidant activity of ZnONPs is likely due to their characteristic physicochemical properties, including a high surface area to volume ratio, that increases their reactivity with free radicals. Incorporation of bioactive molecules from the peels of bitter gourd fruits into the nanoparticle matrix likely increases the activity further, offering a strong protective mechanism against oxidative stress (Kumar *et al.*, 2020) [3].

The ZnONPs prepared from fruit peels were shown to have a significantly enhanced antidiabetic activity over that of the crude extract. The possible reason for this increase is that the active components are having greater bioavailability and cell penetration when presented in nanoparticulate form. The findings indicate that ZnONPs may be a good option for diabetes management, especially under resource-poor environments where waste in the kitchen can be used to prepare these nanoparticles (Ahmed *et al.*, 2017) [1].

The increased anti-inflammatory and antimicrobial activity of ZnONPs aligns with the established properties of zinc oxide as well as with the phytochemical compounds found in bitter gourd. Penetration and interaction with microbial membranes and inflammatory mechanisms by nanoparticles more than crude extracts render them extremely effective. Fruit peels are not only utilized to reduce kitchen waste to a minimum but also help in designing newer antimicrobial and anti-inflammatory drugs that would meet the increasing problem of antibiotic resistance.

Conclusion

This research effectively showed the increased bioactivity of bitter gourd fruit peel-derived ZnONPs. The ZnONPs had better antioxidant, antidiabetic, anti-inflammatory, and antimicrobial activities than crude extracts. Through the use of kitchen waste, this research benefits environmental sustainability as well as provides an economical and environmentally friendly method for developing effective therapeutic agents. These results confirm the promise of ZnONPs as a useful substitute for treating numerous illnesses, such as microbial diseases and diabetes, and open the door to research into the application of waste from the kitchen in nanotechnology in the future.

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