Synthesis, Characterization, and In-Vitro Bioactivity Studies of Coffea Arabica -Mediated Zirconium Oxide Nanoparticles Decorated With Quercetin in Preventive Dentistry

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**Abstract:** In the realm of oral implantology research, the convergence of antioxidants and nanoparticles has garnered escalating attention, driven by their potential to bolster implant efficacy and augment oral health. The pivotal role of antioxidant and anti-inflammatory agents in cultivating oral well-being within implant procedures has surged to the forefront. The exceptional mechanical and chemical attributes of zirconium have propelled its prominence in this arena. This investigation capitalizes on the utilization of *Coffea arabica* as a natural capping agent for zirconium oxide nanoparticle synthesis and further functionalization with quercetin, thereby advancing our understanding of their prospective utility in oral implantology. The core objective of this study revolves around the establishment of a green synthesis methodology for generating zirconium oxide nanoparticles, specifically C-ZrO2NPs, facilitated by *Coffea arabica* and quercetin. The nanoparticles were meticulously synthesized using this approach and subjected to thorough characterization through an array of techniques, encompassing UV-visible spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, Scanning electron microscopy, and EDX analysis. Noteworthy outcomes emerged from in vitro bioactivity assessments, revealing that CQZN exhibits substantial anti-inflammatory and commendable antioxidant attributes. These promising findings underscore the potential of CQZN, underscoring the need for further comprehensive investigations to unravel their full efficacy and potential toxicity aspects in the context of oral implantology.

**Keywords:** Zirconium oxide nanoparticles, *Coffea arabica,* quercetin, antioxidant, anti-inflammatory, dental implants

# INTRODUCTION

Metals are currently fabricated into nanoscale for a wide range of applications in the fields of medicine, biomedical research, environmental engineering, etc. They are currently synthesized using chemical methods which can cause harmful effects on the environment, eventually leading to potential health risks. [(Tiwari & Jain, 2023)](https://paperpile.com/c/kVNsG0/zlS5b)[(Graf et al., 2023)](https://paperpile.com/c/kVNsG0/XEGEJ) Therefore, the green synthesis method is employed to reduce the cost of synthesis, environmental pollution, health risks, energy consumption, etc [(Ying et al., 2022)](https://paperpile.com/c/kVNsG0/WXCGq). This method employs the use of plant sources or microorganisms as a reducing agent and also as a capping agent [(Devi et al., 2019)](https://paperpile.com/c/kVNsG0/zRAuZ). The phytocompounds present in natural sources act as a chemical agent in reducing metal ions. In this study, we have used zirconium which is a transition metal and possesses strong activity against corrosion, high toughness, stability, resistance, color stability, displacement resistance, and strength [(Abhay et al., 2021; Hu et al., 2019)](https://paperpile.com/c/kVNsG0/q2lIH+7xhRv). Zirconia is widely used in the application of dental implants due to its natural color [(Chau et al., 2022; Pandurangan et al., 2020)](https://paperpile.com/c/kVNsG0/hohL8+In8Ft). Coffee beans, commonly enjoyed for their rich aroma and flavorful brews, have recently gained attention in science and technology. Through innovative techniques, scientists have harnessed the unique properties of coffee beans to create nanoparticles that possess remarkable applications in various fields, including medicine, electronics, and environmental remediation [(Baghaienezhad et al., 2020)](https://paperpile.com/c/kVNsG0/6BVS)[(Dharman 2021)](https://paperpile.com/c/kVNsG0/lmME8).

In oral implantology, a contemporary emphasis on proactive approaches is reshaping dental outcomes. This shift goes beyond traditional methods, aiming to optimize implant success proactively. Rooted in solid medical and dental foundations, oral implantology incorporates extensively studied techniques, combining clinical expertise, patient involvement, and scientific progress.[(Neha et al., 2021)](https://paperpile.com/c/kVNsG0/K3Fd)[(Maliael et al., 2021)](https://paperpile.com/c/kVNsG0/VbAol)[(Lakshmi, 2021)](https://paperpile.com/c/kVNsG0/y7eUD) This exploration delves into the field's core medical principles, pioneering implant methods, and contributions to lasting oral well-being, while also examining its current lacunae and recent advancements [(Boyce, 2021; Gallucci et al., 2018)](https://paperpile.com/c/kVNsG0/YJYkm+HwIXX).

Therefore, this study uses *Coffea arabica* as a reducing agent of C-ZrO2NPs. [(Tiwari & Jain, 2023)](https://paperpile.com/c/kVNsG0/zlS5b)[(Graf et al., 2023)](https://paperpile.com/c/kVNsG0/XEGEJ) Therefore, this study focuses on synthesizing the nanoparticles using *Coffea arabica* and capping the nanoparticles using quercetin.[(Jabin et al., 2021)](https://paperpile.com/c/kVNsG0/cCoQ)[(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/kVNsG0/oJzhe) [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/kVNsG0/yj3nc).These nanoparticles are then characterized using UV-Vis spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, Scanning electron microscopy, and EDX.[(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/kVNsG0/9Yl5f)[(Sushanthi et al., 2021)](https://paperpile.com/c/kVNsG0/lYwiK)[(Harsha et al., 2022)](https://paperpile.com/c/kVNsG0/GEMLK). The bioactivity was evaluated using the anti-inflammatory[(Ramamurthy & Jayakumar, 2020)](https://paperpile.com/c/kVNsG0/TpSul) and anti-oxidant assay with reference to previous literature [(Imtiaz et al., 2021)](https://paperpile.com/c/kVNsG0/2vIZh) [(Harsha & Subramanian, 2022)](https://paperpile.com/c/kVNsG0/ApYXb)[(Deepika et al., 2022)](https://paperpile.com/c/kVNsG0/1pqMr)[(Solanki et al., 2022)](https://paperpile.com/c/kVNsG0/V0KFA). This study shows only the preliminary analysis of CQZN, further extensive analysis needs to be done to evaluate its efficacy and toxicity.

# MATERIALS AND METHODS

## Sample Collection and Authentication

The study utilized *Coffea arabica* bean extract for nanoparticle synthesis. Authenticated coffee beans were obtained from commercial suppliers in Chennai, India, with botanical verification conducted by a qualified taxonomist.

## Chemicals and Reagents

High-purity zirconium isopropoxide (precursor material), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and quercetin (standard antioxidant) were sourced from SRL Chemicals. All other chemicals were of analytical grade, with experiments conducted using Milli-Q water purification system water.

## Aqueous Extract Preparation

Roasted *C. arabica* beans were mechanically pulverized to coarse consistency. An aqueous extract was prepared by refluxing 2 g of powdered material in 50 mL double-distilled water at 100°C for 30 minutes, followed by filtration through Whatman No. 1 filter paper. The resultant filtrate served as the reducing agent for subsequent nanoparticle synthesis.

## Synthesis of Coffee-Mediated Zirconia Nanoparticles (C-ZrO₂NPs)

The biosynthesis involved dropwise addition of 3 mL zirconium(IV) isopropoxide to ammoniated coffee extract under continuous magnetic stirring (500 rpm). The resulting colloidal suspension was maintained at 60°C for 2 hours with constant agitation. The precipitated nanoparticles were isolated via centrifugation (10,000 × g, 15 min), washed thrice with acetone, and oven-dried at 70°C for 12 hours.

## Surface Functionalization with Quercetin

For bioactive conjugation, 200 mg of C-ZrO₂NPs were dispersed in 20 mL polyethylene glycol 4000 solution (0.05% w/v) under ambient conditions. After 1 hour homogenization, 20 mg/mL quercetin solution (in DMSO) was incorporated with 30 minutes stirring. The quercetin-functionalized nanoparticles (CQZN) were recovered by centrifugation (8,000 rpm, 10 min), lyophilized, and stored for characterization.

## Physicochemical Characterization

Nanoparticle suspensions in deionized water underwent comprehensive analysis:

* Optical properties by UV-Vis spectroscopy (200-800 nm)
* Hydrodynamic diameter and zeta potential via dynamic light scattering
* Functional group identification using FTIR-ATR (4000-500 cm⁻¹)
* Crystallinity assessment by XRD (20°-80° 2θ, Cu-Kα radiation)
* Surface morphology and elemental composition through SEM-EDX

## Antioxidant Capacity Assessment

The DPPH radical scavenging assay was performed by incubating 1.5 mL of 0.1 mM DPPH (methanolic) with varying CQZN concentrations (25-200 μg/mL) for 20 minutes at 27°C [(Rather et al., 2017)](https://paperpile.com/c/kVNsG0/d4S4y),[(Shahid-Ul-Islam et al., 2019)](https://paperpile.com/c/kVNsG0/stdGg). Absorbance measurements at 517 nm enabled calculation of radical quenching efficiency:  
% Scavenging = [(Acontrol - Asample)/Acontrol] × 100

## Protein Denaturation Inhibition Assay

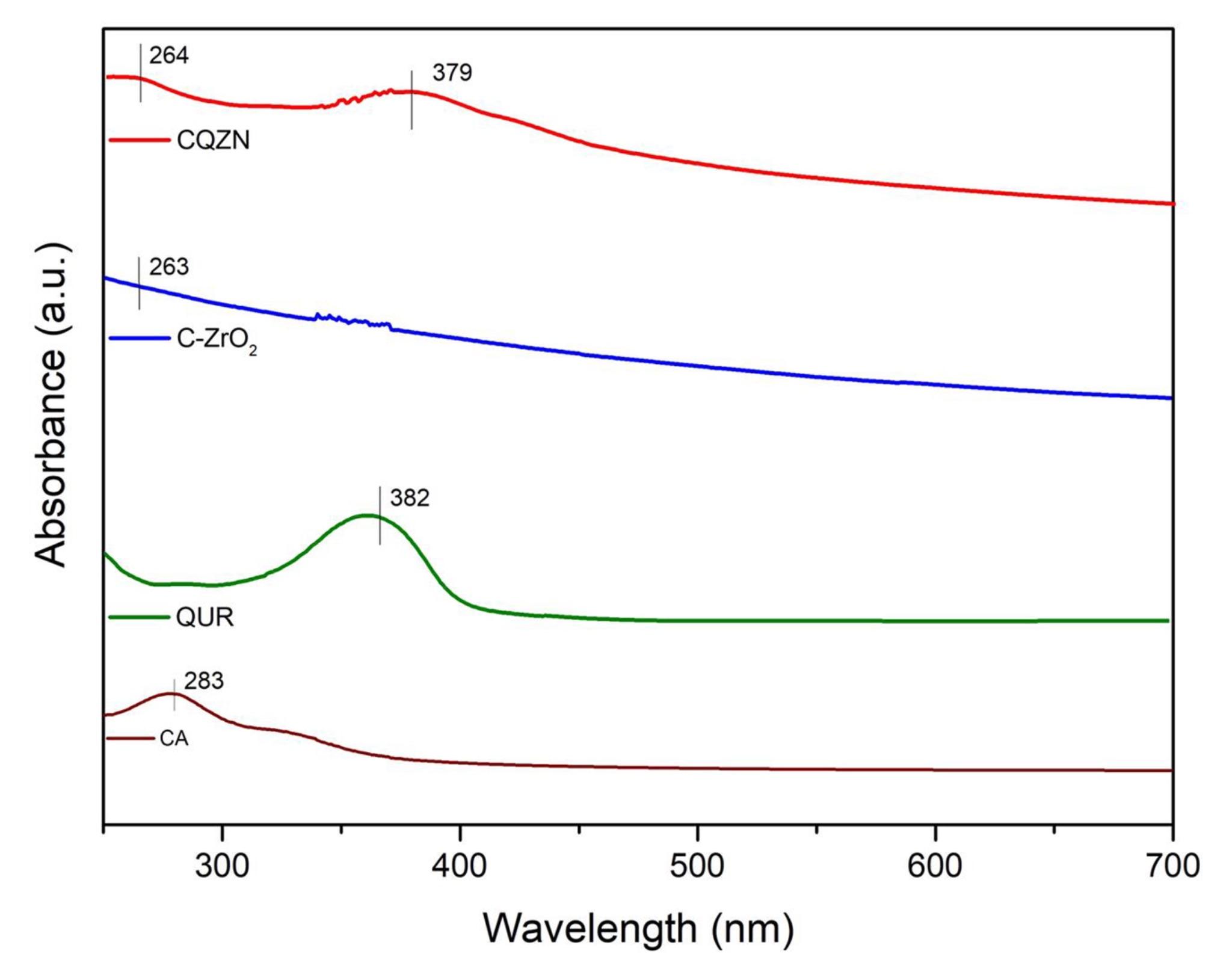
Anti-inflammatory activity was evaluated through bovine serum albumin (BSA) denaturation inhibition [(Pandiyan et al., 2022)](https://paperpile.com/c/kVNsG0/mm2BN). Test samples (25-200 μg/mL in PBS) were combined with 1% BSA, incubated at 37°C (20 min) followed by 75°C (10 min). After thermal treatment, absorbance at 660 nm determined protein protection efficacy using the standard inhibition formula [(Bhattacharya et al., 2012; Chandra et al., 2012; Jayavarsha et al., 2022; Kedi et al., 2018)](https://paperpile.com/c/kVNsG0/dQOti+WYZGs+Urjrd+AvgLj)**.**

# RESULTS

In this current study, the synthesis of C-ZrO2NPs and the capping of the nanoparticles using quercetin were performed. These nanoparticles are then characterized using UV-Vis spectroscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, Scanning electron microscopy, and EDX. The biocompatibility study was done by performing the hemolytic assay and its bioactivity was evaluated using the anti-inflammatory and anti-microbial assay.

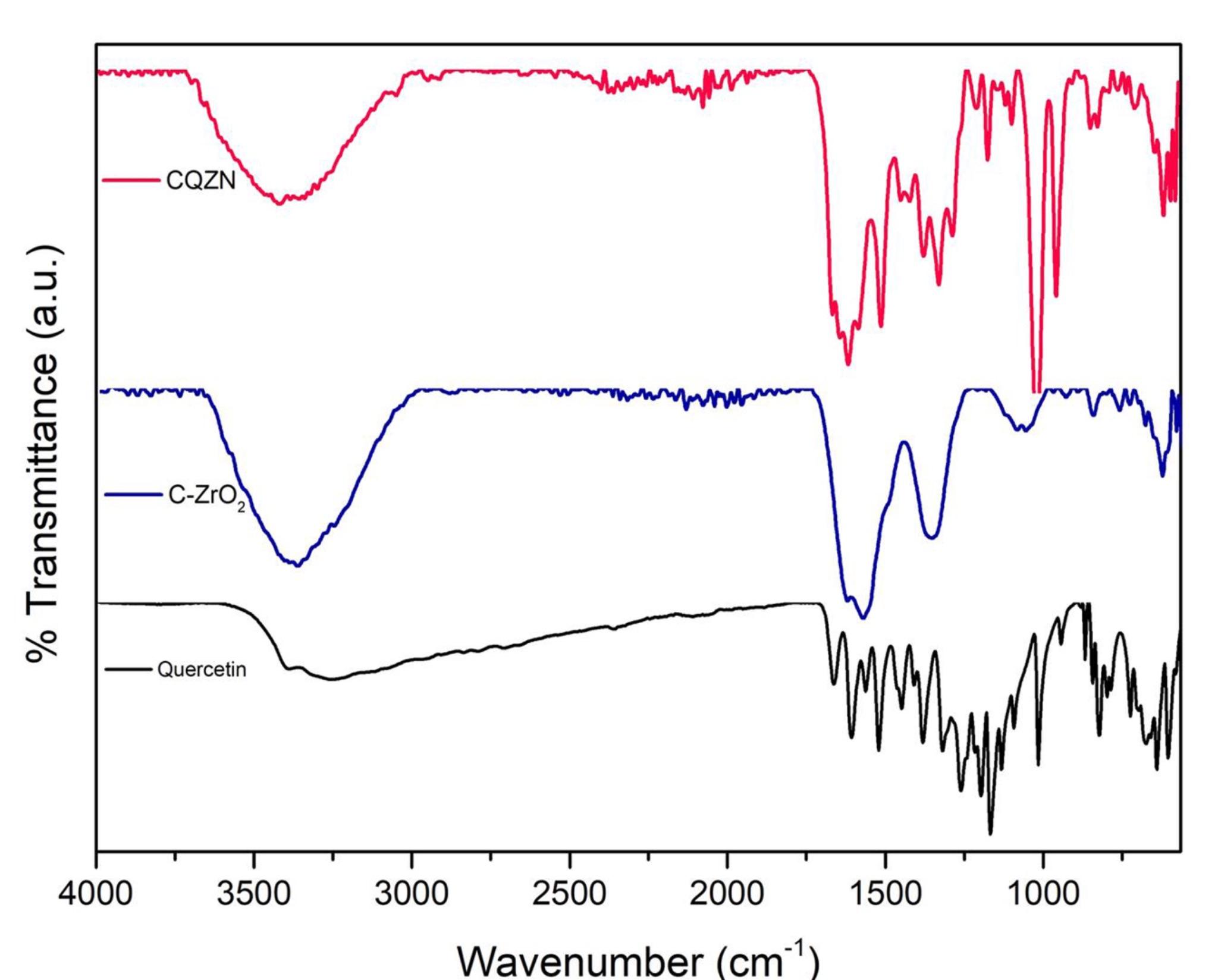
## Characterization of Nanoparticles

The UV- Visible spectral analysis for CQZN and C-ZrO2NPs showed a typical surface plasmon resonance (SPR) peak with maximum absorbance at 263 nm and 379 nm respectively confirming the ZrO2 NPs formation, which is evidenced by the shift in maximum absorbance compared to the extract. Figure 1 represents the UV spectra of CQZN.



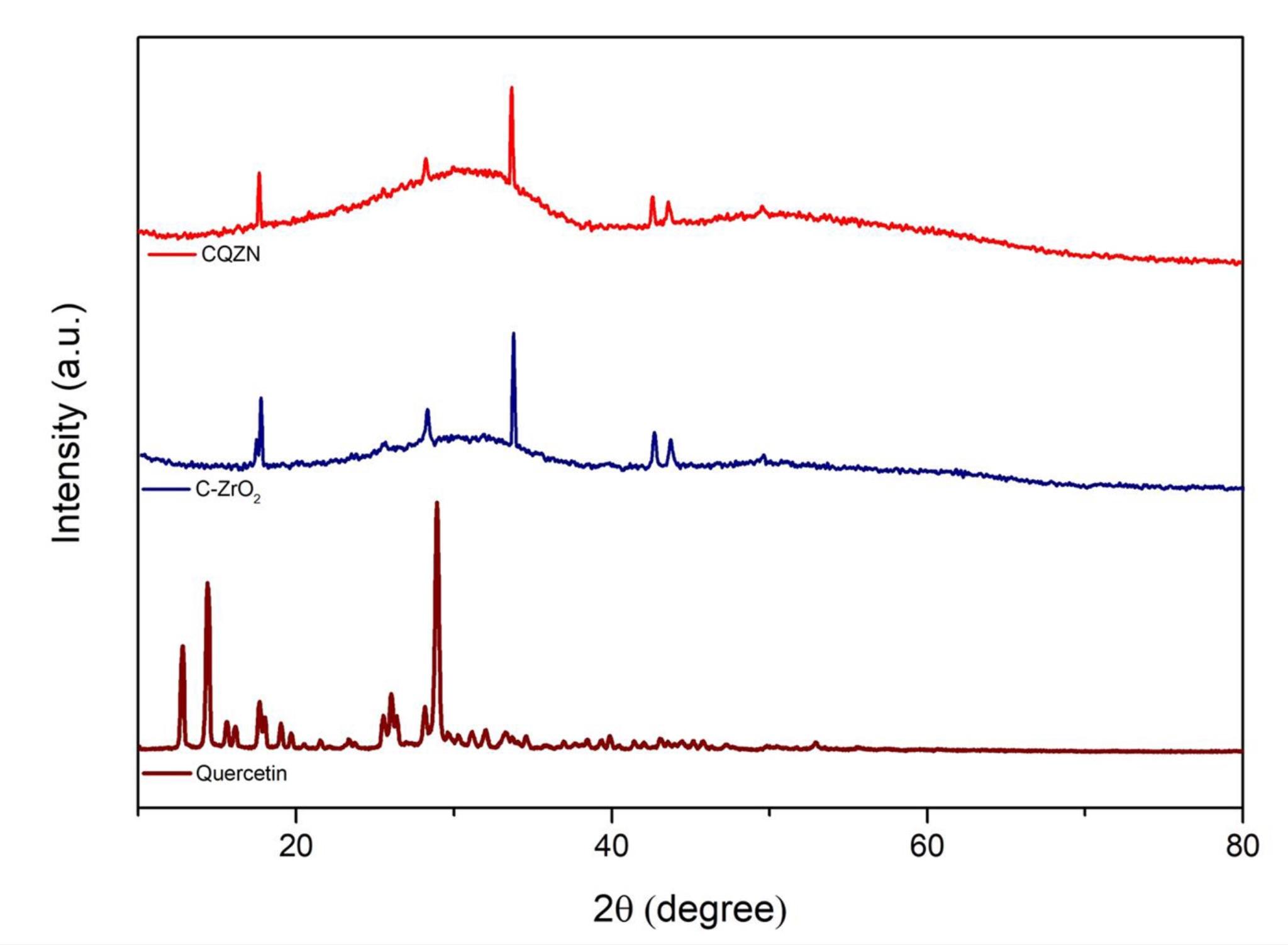
**Figure 1.** UV spectra of C-ZrO2NPs and CQZN

FT-IR spectra were recorded between 4000 to 500 cm-1. Figure 2 represents the result of the synthesized CQZN and C-ZrO2NPs. The FT-IR spectrum of C-ZrO2NPs showed strong absorption bands at 3372, 2138, 1574, 1356, 1060, 761 and 625 cm-1. Characteristic stretching at 3372 cm-1 confirms the OH group present in the extract used for C-ZrO2NPs formation, which is evidenced by the shift in maximum absorbance compared to the extract. Similarly, the FT-IR spectrum of CQZN showed strong absorption bands at 3372, 2369, 2330, 1598, 1496 1315, 1163, 1009 and 949 cm-1. Characteristic stretching at 3372 cm-1 confirms the OH group present in the extract used for CQZN formation, which is evidenced by the shift in maximum absorbance compared to the extract.



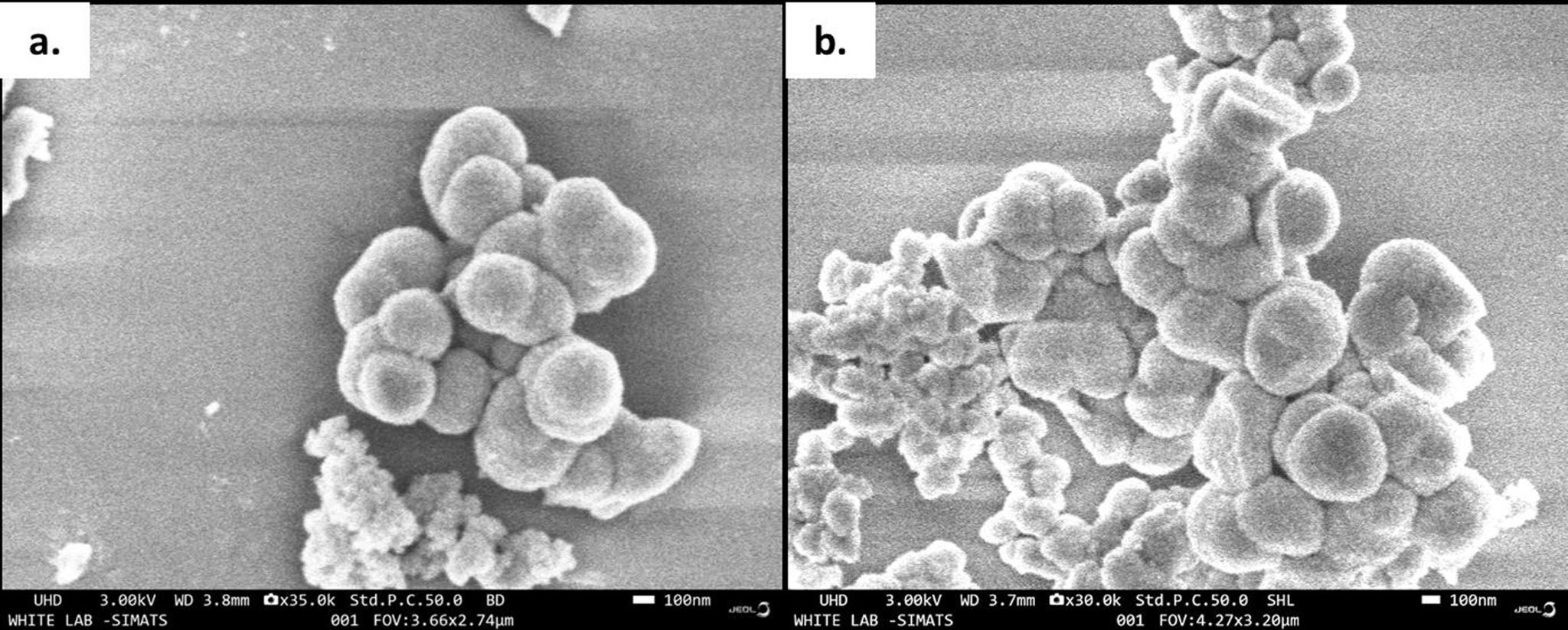
**Figure 2** FT-IR spectra of Qur, C-ZrO2, and CQZN

Figure 3 represents the XRD pattern of Qur, C-ZrO2, and CQZN displays several sharp peaks. The positions of the peaks were compared to the elements reported in the JCPDS database, which revealed that the sample has a monoclinic crystal structure, consistent with ZrO2. The peak observed at 10° indicates the successful coating of quercetin on C-ZrO2NPs.

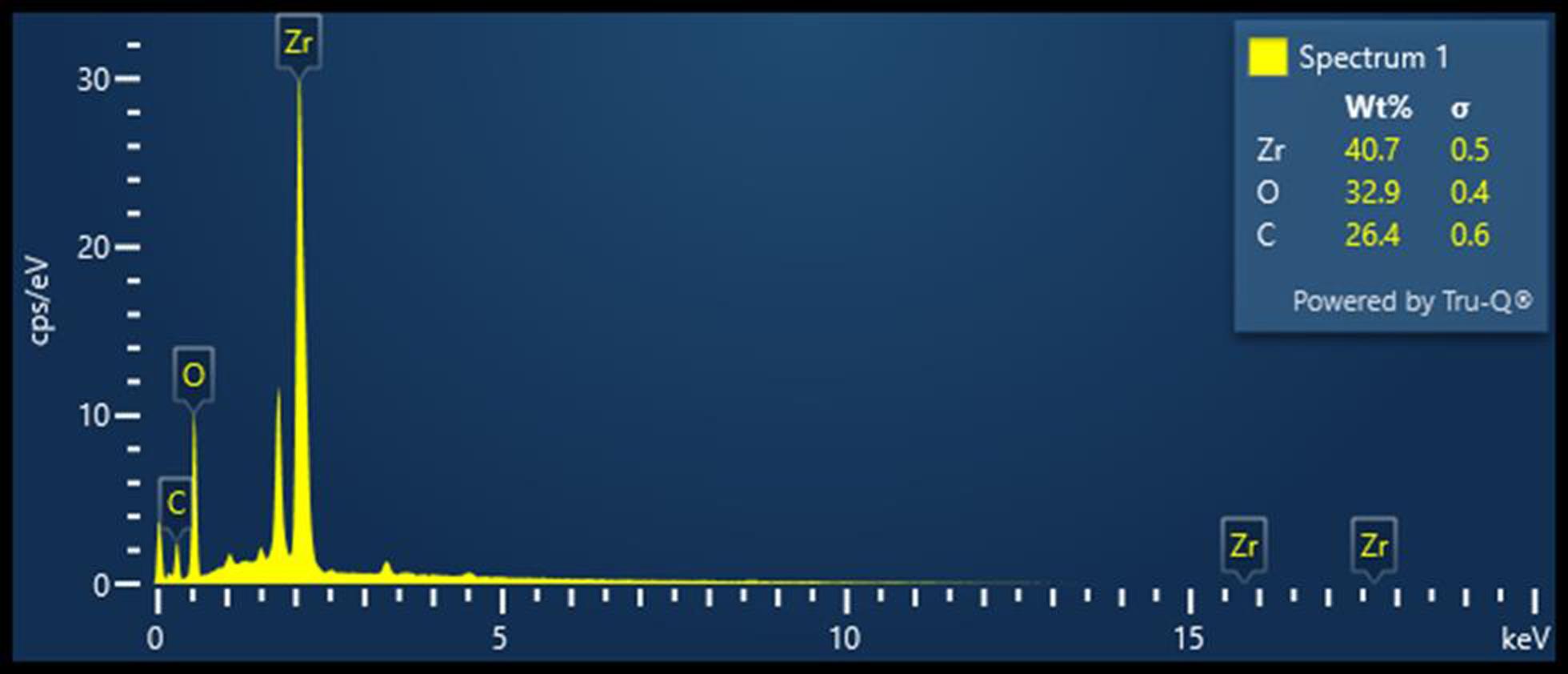


**Figure 3** XRD pattern of Qur, C-ZrO2, and CQZN

The morphology of the synthesized nanoparticles was determined by scanning electron microscopy. The CQZN exhibits spherical shaped particles with a size range of around 120 nm. On the other hand, the coating of quercetin increases the particle size to 150 nm. Figure 4 represents the morphology of C-ZrO2NPs and CQZN. EDAX spectrum showed of 40.7 wt % of zirconium in the green synthesized CQZN. This result confirms the formation of CQZN. Figure 5 represents the EDAX spectrum of synthesized CQZN.



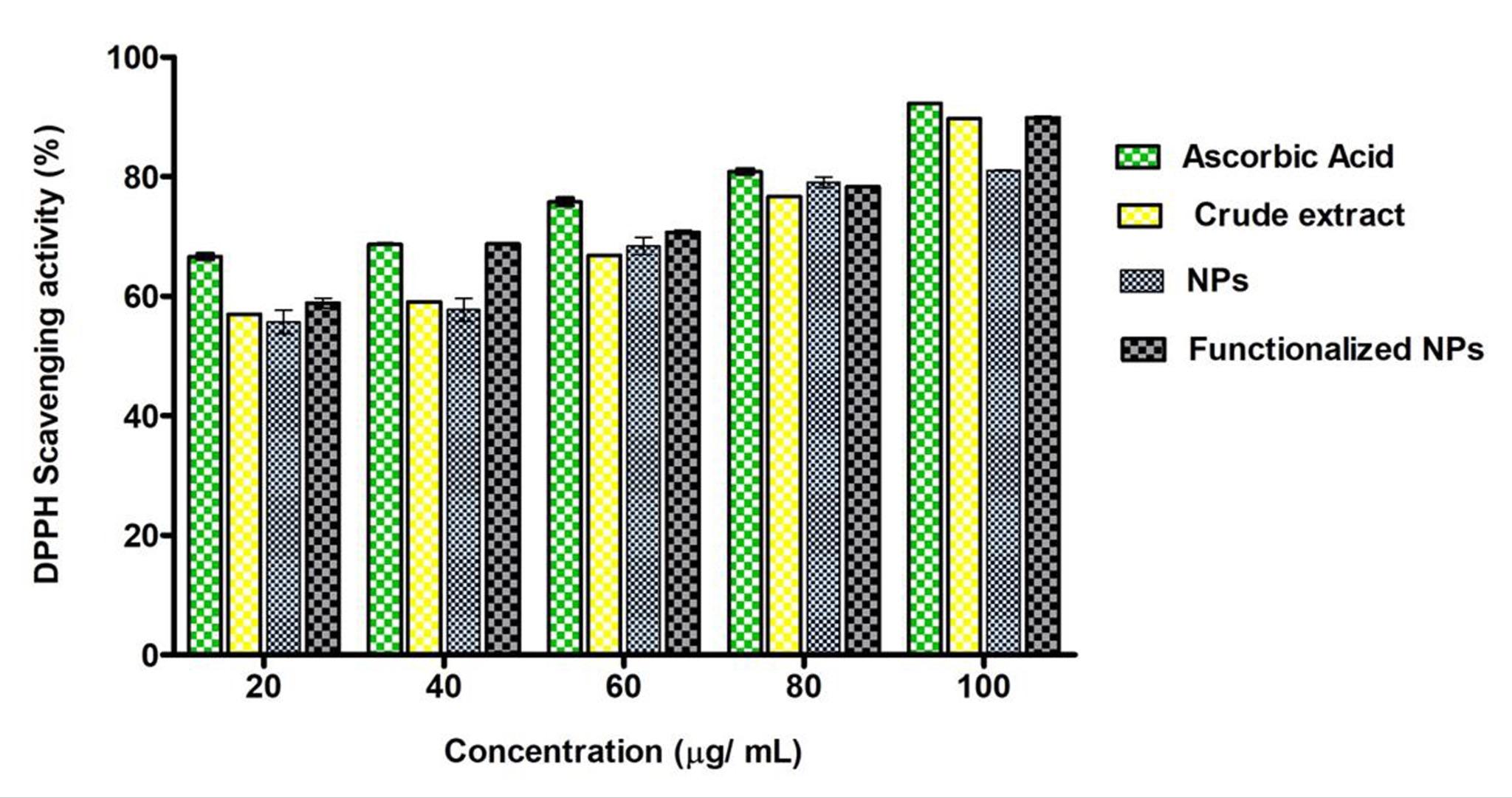
**Figure 4 (a) (b)** SEM micrograph of C-ZrO2NPs (a) and CQZN (b)



**Figure 5** represents the EDAX spectrum of CQZN

## In-vitro Anti-oxidant Activity

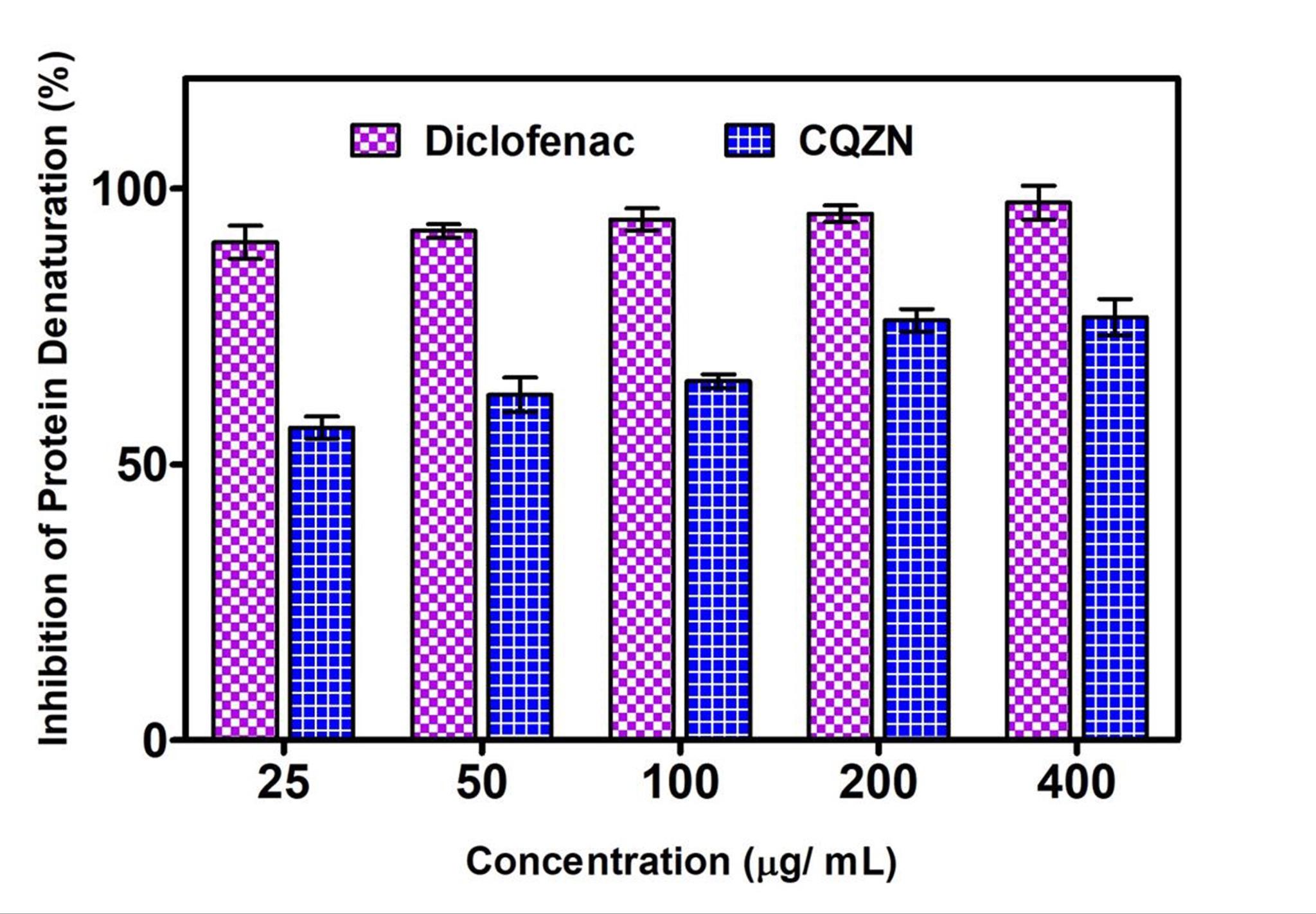
The DPPH assay was used to assess the in vitro antioxidant activity of *Coffea arabica* crude extract, C-ZrO2NPs, and CQZN. The sample's ability to scavenge free radicals is directly correlated with the decline in DPPH radical absorbance. A dose-dependent rise in the DPPH radical's % inhibition was observed. The percentage of suppression of the DPPH radical at the maximum concentration tested (100 g/mL) was found to be 79.8 1.2% (Figure 6).



**Figure 6** Anti-oxidant activity of C-ZrO2, and CQZN. Experiment was performed in triplicates and values are expressed in mean ±S.D.

## In-vitro Anti-inflammatory Activity

The *in vitro* anti-inflammatory assay results showed that CQZN created using *Coffea arabica* bean extract substantially and dose-dependently reduced the denaturation of BSA (Figure 7). This suggests that the nanoparticles have the potential to have an anti-inflammatory effect and could be applied to the creation of new anti-inflammatory drugs.



**Figure 7** Anti-inflammatory activity of CQZN. Experiment was performed in triplicates and values are expressed in mean ±S.D.

# DISCUSSION

The optical properties of the coffee-mediated zirconia nanoparticles (C-ZrO₂NPs) were characterized using UV-Vis spectroscopy, revealing a distinct absorption peak between 250-280 nm that confirms successful nanoparticle synthesis [(Smits et al., 2011)](https://paperpile.com/c/kVNsG0/UHdTa). The broad absorption band observed in the visible region corresponds to surface plasmon resonance, a phenomenon well-documented in previous studies [(Khan et al., 2020)](https://paperpile.com/c/kVNsG0/qH8xa). This optical characteristic demonstrates size-dependent behavior, where smaller nanoparticles exhibit higher resonance frequencies, while the symmetrical nature of the absorption band suggests predominantly spherical morphology [(Chelliah et al., 2023)](https://paperpile.com/c/kVNsG0/TCkn2). These findings align with established principles of nanoparticle optics and provide valuable insights into the size distribution and shape characteristics of the synthesized particles [(Terki et al., 2006)](https://paperpile.com/c/kVNsG0/OeMT4).

Fourier-transform infrared spectroscopy analysis identified several functional groups present on the nanoparticle surfaces. The spectrum showed characteristic absorption bands corresponding to various molecular vibrations, including N-H stretching of primary amines, C=C stretching of cyclic alkenes, and C-O stretching of alcohol groups. These spectral features confirm the presence of organic capping agents derived from the coffee extract that stabilize the nanoparticles. The quercetin-functionalized nanoparticles exhibited additional peaks characteristic of the conjugated flavonoid molecules, verifying successful surface modification. These spectroscopic findings are consistent with previous reports on similar nanoparticle systems.

X-ray diffraction analysis confirmed the monoclinic crystal structure of the zirconia nanoparticles, with lattice parameters matching standard reference patterns [(Hossain et al., 2023)](https://paperpile.com/c/kVNsG0/GsE1H). The observed peak broadening suggests moderate size distribution within the nanoparticle population while maintaining high crystallinity(Chehelgerdi et al., 2023). Scanning electron microscopy revealed well-dispersed spherical nanoparticles with an average size of approximately 50 nm and smooth surface morphology. The homogeneous distribution and minimal aggregation observed in the micrographs indicate effective stabilization of the nanoparticles during the synthesis process.

Biological evaluation demonstrated that the functionalized nanoparticles possess moderate anti-inflammatory activity through inhibition of protein denaturation, though less potent than standard controls [(Balaji et al., 2017)](https://paperpile.com/c/kVNsG0/iq6ct). Antioxidant assessment revealed significant free radical scavenging capacity, with the crude coffee extract showing slightly higher activity than the nanoparticles, possibly due to differences in bioactive compound accessibility after functionalization (Saadh et al., 2024). These findings suggest potential biomedical applications for the nanoparticles in managing oxidative stress and inflammation-related conditions.

The successful green synthesis of quercetin-functionalized zirconia nanoparticles using coffee extract presents promising opportunities for therapeutic applications. The nanoparticles' demonstrated bioactivities, combined with their favorable physicochemical properties, make them particularly interesting for potential use in oral healthcare applications. However, comprehensive toxicological evaluation and further optimization of the synthesis process will be necessary before clinical translation. Future studies should focus on detailed mechanistic investigations and in vivo evaluations to fully explore the therapeutic potential of these novel nanoparticles. The current findings provide a solid foundation for further development of these nanoparticles as potential therapeutic agents in dentistry and related fields.

# CONCLUSION

In recent times, the realm of nanotechnology has undergone rapid transformation, transitioning from experimental settings to widespread industrial integration across pharmaceuticals, medicine, and biomedical domains. These strides are particularly significant within the realm of oral implantology. This study contributes by championing the eco-friendly synthesis of C-ZrO2NPs, offering potential dental applications. Rigorous characterization techniques, encompassing UV spectrophotometry, FTIR, SEM, and EDAX analyses, have successfully validated the structure and composition of CQZN. Particularly noteworthy is CQZN's robust antioxidant activity, a pivotal trait in oral health contexts. The biocompatibility and minimal cytotoxicity of green synthesis-mediated ZrO2NPs pave the way for enriched dental therapies and preventive strategies. This study not only enriches our comprehension of sustainable nanoparticle synthesis but also unveils new avenues for pioneering research in oral implantology, with the potential for enduring impacts on oral healthcare practices.

# References

1. [Abhay, S. S., Ganapathy, D., Veeraiyan, D. N., Ariga, P., Heboyan, A., Amornvit, P., Rokaya, D., & Srimaneepong, V. (2021). Wear Resistance, Color Stability and Displacement Resistance of Milled PEEK Crowns Compared to Zirconia Crowns under Stimulated Chewing and High-Performance Aging. *Polymers*, *13*(21). https://doi.org/](http://paperpile.com/b/kVNsG0/7xhRv)[10.3390/polym13213761](http://dx.doi.org/10.3390/polym13213761)
2. [Baghaienezhad, M., Boroghani, M., & Anabestani, R. (2020). Silver nanoparticles Synthesis by coffee residues extract and their antibacterial activity. *Nanomedicine Research Journal*, *5*(1), 29–34.](http://paperpile.com/b/kVNsG0/6BVS)
3. [Balaji Ganesh S, & Sugumar, K. (2021). Internet of Things—A novel innovation in dentistry. *Journal of Advanced Oral Research*, *12*(1), 42–48.](http://paperpile.com/b/kVNsG0/oJzhe)
4. [Balaji, S., Mandal, B. K., Ranjan, S., Dasgupta, N., & Chidambaram, R. (2017). Nano-zirconia - Evaluation of its antioxidant and anticancer activity. *Journal of Photochemistry and Photobiology. B, Biology*, *170*, 125–133.](http://paperpile.com/b/kVNsG0/iq6ct)
5. [Bhattacharya, S., Chandra, S., Chatterjee, P., & Dey, P. (2012). Evaluation of anti-inflammatory effects of green tea and black tea: A comparative in vitro study. In *Journal of Advanced Pharmaceutical Technology & Research* (Vol. 3, Issue 2, p. 136). https://doi.org/](http://paperpile.com/b/kVNsG0/Urjrd)[10.4103/2231-4040.97298](http://dx.doi.org/10.4103/2231-4040.97298)
6. [Boyce, R. A. (2021). Prosthodontic Principles in Dental Implantology: Adjustments in a Coronavirus Disease-19 Pandemic-Battered Economy. *Dental Clinics of North America*, *65*(1), 135–165.](http://paperpile.com/b/kVNsG0/HwIXX)
7. [Chandra, S., Chatterjee, P., Dey, P., & Bhattacharya, S. (2012). Evaluation of anti-inflammatory effect of ashwagandha: A preliminary study in vitro. *Pharmacognosy Journal*, *4*(29), 47–49.](http://paperpile.com/b/kVNsG0/WYZGs)
8. [Chau, T. P., Veeraragavan, G. R., Narayanan, M., Chinnathambi, A., Alharbi, S. A., Subramani, B., Brindhadevi, K., Pimpimon, T., & Pikulkaew, S. (2022). Green synthesis of Zirconium nanoparticles using Punica granatum (pomegranate) peel extract and their antimicrobial and antioxidant potency. *Environmental Research*, *209*, 112771.](http://paperpile.com/b/kVNsG0/hohL8)
9. Chehelgerdi M., Chehelgerdi, M., Allela, O. Q. B., Pecho, R. D. C., Jayasankar, N., Rao, D. P. & Akhavan-Sigari, R. (2023). Progressing nanotechnology to improve targeted cancer treatment: overcoming hurdles in its clinical implementation. Molecular cancer, 22(1), 169.
10. [Chelliah, P., Wabaidur, S. M., Sharma, H. P., Majdi, H. S., Smait, D. A., Najm, M. A., Iqbal, A., & Lai, W.-C. (2023). Photocatalytic Organic Contaminant Degradation of Green Synthesized ZrO2 NPs and Their Antibacterial Activities. *Separations Technology*, *10*(3), 156.](http://paperpile.com/b/kVNsG0/TCkn2)
11. [Deepika, B. A., Ramamurthy, J., Girija, S., & Jayakumar, N. D. (2022). Evaluation of the antimicrobial effect of Ocimum sanctum L. oral gel against anaerobic oral microbes: An in vitro study. *World Journal of Dentistry*, *13*(S1), S23–S27.](http://paperpile.com/b/kVNsG0/1pqMr)
12. [Devi, H. S., Boda, M. A., Shah, M. A., Parveen, S., & Wani, A. H. (2019). Green synthesis of iron oxide nanoparticles using Platanus orientalis leaf extract for antifungal activity. *Green Processing and Synthesis*, *8*(1), 38–45.](http://paperpile.com/b/kVNsG0/zRAuZ)
13. [Dharman, S (2021). Ecofriendly Synthesis, Characterisation and Antibacterial Activity Of Curcumin Mediated Silver Nanoparticles. *International Journal of Dentistry and Oral Science*, 2314–2318.](http://paperpile.com/b/kVNsG0/lmME8)
14. [Gallucci, G. O., Hamilton, A., Zhou, W., Buser, D., & Chen, S. (2018). Implant placement and loading protocols in partially edentulous patients: A systematic review. *Clinical Oral Implants Research*, *29 Suppl 16*, 106–134.](http://paperpile.com/b/kVNsG0/YJYkm)
15. [Govindaraj, A., & Dinesh, S. P. S. (2021). Effect of chlorhexidine varnish and fluoride varnish on White Spot Lesions in orthodontic patients- a systematic review. *The Open Dentistry Journal*, *15*(1), 151–159.](http://paperpile.com/b/kVNsG0/yj3nc)
16. [Graf, S., Thakkar, D., Hansa, I., Pandian, S. M., & Adel, S. M. (2023). 3D metal printing in orthodontics current trends, biomaterials, workflows and clinical implications. *Seminars in Orthodontics*. https://doi.org/](http://paperpile.com/b/kVNsG0/XEGEJ)[10.1053/j.sodo.2023.01.001](http://dx.doi.org/10.1053/j.sodo.2023.01.001)
17. [Harsha, L., Navaneethan, R., Acid, T., & Acid, C. A.-A. (2022). CITRIC ACID-AN VITRO STUDY. *International Journal Clinical Dentistry*, *15*(3), 413–419.](http://paperpile.com/b/kVNsG0/GEMLK)
18. [Harsha, L., & Subramanian, A. K. (2022). Comparative assessment of pH and degree of surface roughness of enamel when etched with five commercially available etchants: An in vitro study. *The Journal of Contemporary Dental Practice*, *23*(2), 181–185.](http://paperpile.com/b/kVNsG0/ApYXb)
19. [Hossain, N., Mobarak, M. H., Hossain, A., Khan, F., Mim, J. J., & Chowdhury, M. A. (2023). Advances of plant and biomass extracted zirconium nanoparticles in dental implant application. *Heliyon*, *9*(5), e15973.](http://paperpile.com/b/kVNsG0/GsE1H)
20. [Hu, C., Sun, J., Long, C., Wu, L., Zhou, C., & Zhang, X. (2019). Synthesis of nano zirconium oxide and its application in dentistry. *Nanotechnology Reviews*, *8*(1), 396–404.](http://paperpile.com/b/kVNsG0/q2lIH)
21. [Imtiaz, T., Priyadharshini, R., Rajeshkumar, S., & Sinduja, P. (2021). Green synthesis and Characterization of Silver Nanoparticles Synthesized Using Piper longum and its Antioxidant Activity. *Journal of Pharmaceutical Research International*, 342–352.](http://paperpile.com/b/kVNsG0/2vIZh)
22. [Jabin, Z., Nasim, I., Vishnu Priya, V., & Agarwal, N. (2021). Quantitative Analysis and Effect of SDF, APF, NaF on Demineralized Human Primary Enamel Using SEM, XRD, and FTIR. *International Journal of Clinical Pediatric Dentistry*, *14*(4), 537–541.](http://paperpile.com/b/kVNsG0/cCoQ)
23. [Jayavarsha, V., Rajeshkumar, S., Lakshmi, T., & Sulochana, G. (2022). Green synthesis of selenium nanoparticles study using clove and cumin and its anti- inflammatory activity. *Journal of Complementary Medicine Research*, *13*(5), 84.](http://paperpile.com/b/kVNsG0/AvgLj)
24. [Kedi, P. B. E., Meva, F. E., Kotsedi, L., Nguemfo, E. L., Zangueu, C. B., Ntoumba, A. A., Mohamed, H. E. A., Dongmo, A. B., & Maaza, M. (2018). Eco-friendly synthesis, characterization, in vitro and in vivo anti-inflammatory activity of silver nanoparticle-mediated aqueous extract. *International Journal of Nanomedicine*, *13*, 8537–8548.](http://paperpile.com/b/kVNsG0/dQOti)
25. [Khan, M., Shaik, M. R., Khan, S. T., Adil, S. F., Kuniyil, M., Khan, M., Al-Warthan, A. A., Siddiqui, M. R. H., & Nawaz Tahir, M. (2020). Enhanced Antimicrobial Activity of Biofunctionalized Zirconia Nanoparticles. *ACS Omega*, *5*(4), 1987–1996.](http://paperpile.com/b/kVNsG0/qH8xa)
26. [Lakshmi, T. (2021). Medicinal value oral health aspects acacia catechu-an update. *International Journal Dentistry Oral ScienceVolume*, *8*, 1399–1401J.](http://paperpile.com/b/kVNsG0/y7eUD)
27. [Maliael, M. T., Subramanian, A. K., & Srirengalakshmi. (2021). Effectiveness of a fluoride-releasing orthodontic primer in reducing demineralization around brackets – a systematic review. *Orthodontic Waves (English Ed.)*, *80*(4), 218–223.](http://paperpile.com/b/kVNsG0/VbAol)
28. [Neha, N., Maiti, S., & Jessy, P. (2021). Adhesion microflora role denitrifies colour stability provisional crowns: in-vitro study. *Int J Dentistry Oral Sci*, *8*(8), 3805–3809.](http://paperpile.com/b/kVNsG0/K3Fd)
29. [Pandiyan, I., Sri, S. D., Indiran, M. A., Rathinavelu, P. K., Prabakar, J., & Rajeshkumar, S. (2022). Antioxidant, anti-inflammatory activity of Thymus vulgaris-mediated selenium nanoparticles: An in vitro study. *Journal of Conservative Dentistry: JCD*, *25*(3), 241–245.](http://paperpile.com/b/kVNsG0/mm2BN)
30. [Pandurangan, K. K., Veeraiyan, D. N., & Nesappan, T. (2020). In vitro evaluation of fracture resistance and cyclic fatigue resistance of computer-aided design-on and hand-layered zirconia crowns following cementation on epoxy dies. *Journal of Indian Prosthodontic Society*, *20*(1), 90–96.](http://paperpile.com/b/kVNsG0/In8Ft)
31. [Ramamurthy, J., & Jayakumar, N. D. (2020). Anti-inflammatory, anti-oxidant effect and cytotoxicity of ocimum sanctum intra oral gel for combating periodontal diseases. *Bioinformation*, *16*(12), 1026–1032.](http://paperpile.com/b/kVNsG0/TpSul)
32. [Rather, L. J., Akhter, S., Padder, R. A., Hassan, Q. P., Hussain, M., Khan, M. A., & Mohammad, F. (2017). Colorful and semi durable antioxidant finish of woolen yarn with tannin rich extract of Acacia nilotica natural dye. In *Dyes and Pigments* (Vol. 139, pp. 812–819). https://doi.org/](http://paperpile.com/b/kVNsG0/d4S4y)[10.1016/j.dyepig.2017.01.018](http://dx.doi.org/10.1016/j.dyepig.2017.01.018)
33. Saadh, M. J., Rasulova, I., Almoyad, M. A. A., Kiasari, B. A., Ali, R. T., Rasheed, T. & Ciongradi, C. I. (2024). Recent progress and the emerging role of lncRNAs in cancer drug resistance; focusing on signaling pathways. Pathology-Research and Practice, 253, 154999.
34. [Sabarathinam, J., & Madhulaxmi, R. (2021). Development anti inflammatory antimicrobial silver nanoparticles coated suture materials. *Int J Dentistry Oral Sci*, *8*(3), 2006–2013.](http://paperpile.com/b/kVNsG0/9Yl5f)
35. [Shahid-Ul-Islam, Butola, B. S., & Verma, D. (2019). Facile synthesis of chitosan-silver nanoparticles onto linen for antibacterial activity and free-radical scavenging textiles. *International Journal of Biological Macromolecules*, *133*, 1134–1141.](http://paperpile.com/b/kVNsG0/stdGg)
36. [Smits, K., Grigorjeva, L., Millers, D., Sarakovskis, A., Grabis, J., & Lojkowski, W. (2011). Intrinsic defect related luminescence in ZrO2. *Journal of Luminescence*, *131*(10), 2058–2062.](http://paperpile.com/b/kVNsG0/UHdTa)
37. [Solanki, L., Shantha Sundari, K. K., Muralidharan, N. P., & Jain, R. (2022). Antimicrobial effect of novel gold nanoparticle oral rinse in subjects undergoing orthodontic treatment: An ex-vivo study. *Journal of International Oral Health: JIOH*, *14*(1), 47.](http://paperpile.com/b/kVNsG0/V0KFA)
38. [Sushanthi, S., Doraikannan, S., Indiran, M., & Rathinavelu, P. (2021). *Rajeshkumar S. Vernonia Amygdalina*. 3330–3334.](http://paperpile.com/b/kVNsG0/lYwiK)
39. [Terki, R., Bertrand, G., Aourag, H., & Coddet, C. (2006). Structural and electronic properties of zirconia phases: A FP-LAPW investigations. *Materials Science in Semiconductor Processing*, *9*(6), 1006–1013.](http://paperpile.com/b/kVNsG0/OeMT4)
40. [Tiwari, A., & Jain, R. K. (2023). Comparative evaluation of White Spot lesion incidence between NovaMin, probiotic, and fluoride containing dentifrices during orthodontic treatment using laser fluorescence - A prospective randomized controlled clinical trial. *Clinical and Investigative Orthodontics*, 1–8.](http://paperpile.com/b/kVNsG0/zlS5b)
41. [Ying, S., Guan, Z., Ofoegbu, P. C., Clubb, P., Rico, C., He, F., & Hong, J. (2022). Green synthesis of nanoparticles: Current developments and limitations. *Environmental Technology & Innovation*, *26*, 102336.](http://paperpile.com/b/kVNsG0/WXCGq)