UNIVERSITI TEKNOLOGI MARA

BULETIN APB

EDISI 16

Jun 2026

AKADEMI PENGAJIAN BAHASA
UNIVERSITI TEKNOLOGI MARA
CAWANGAN NEGERI SEMBILAN
KAMPUS SEREMBAN

e-ISSN : 2682-7948

Zinc Oxide Nanoparticles in Food Technology

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In modern food systems, maintaining quality, safety, and nutritional value remains a major challenge. Conventional preservation methods often rely on synthetic additives, raising concerns over health and environmental sustainability. As a result, research is increasingly focused on translating scientific innovation into practical solutions that deliver real-world impact. One promising advancement is the use of zinc oxide nanoparticles (ZnO NPs), which offer multifunctional properties applicable across food preservation, packaging, and nutrition. Notably, ZnO NPs can be biosynthesized directly from sustainable biomaterials.

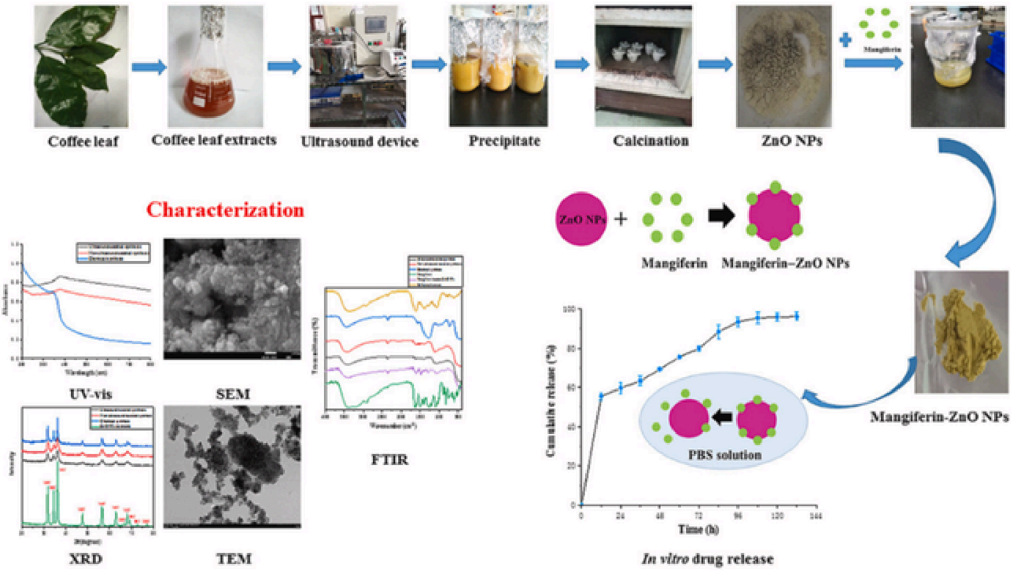
In fruit preservation, the key application of ZnO NPs lies in their antimicrobial activity. Mechanistically, they generate reactive oxygen species (ROS), including hydroxyl radicals and superoxide ions, which damage microbial lipids, proteins, and DNA. Additionally, ZnO NPs disrupt cell membrane integrity and release Zn^{2+} ions that interfere with the enzymatic processes of the fruit. These combined effects make them highly effective against foodborne pathogens (Ahmad & Sarbon, 2021). For example, ZnO NP coatings applied to harvested strawberries have been shown to inhibit microbial growth and significantly delay spoilage (Sani et al., 2025). ZnO NPs also function as antioxidants, particularly in lipid-rich foods where oxidation leads to rancidity. By scavenging free radicals and inhibiting lipid peroxidation, they help preserve flavour, aroma, and nutritional quality (Mohammed et al., 2025). This is especially relevant in edible oils and snack products, where ZnO incorporation can slow oxidative degradation and extend shelf stability during storage.

In active packaging systems, ZnO NPs are incorporated into polymer matrices to create functional films and coatings (Lubis et al., 2020). These films/coatings can interact with gases such as ethylene and carbon dioxide to slow fruit ripening. Furthermore, their nanoscale structure enhances barrier properties against oxygen and moisture. ZnO-infused packaging films/coatings have been used for harvested bananas and tomatoes (Santhosh & Sarkar, 2022) to reduce microbial contamination and prolong shelf life during distribution (La et al., 2021).

ZnO NPs are also utilised in nutrient delivery systems, where they serve as carriers for bioactive compounds. Through nanoencapsulation, sensitive nutrients such as fat-soluble vitamins are protected from degradation. Their small size increases surface area and solubility, improving bioavailability and absorption in the gastrointestinal tract (Wang et al., 2022). A practical example is fortified beverages, in which nano-delivery systems enhance the stability and uptake of vitamin D. As a zinc-fortification agent, ZnO NPs provide an efficient means of addressing micronutrient deficiencies (Chen et al., 2025). The nanoscale form enhances dissolution rate and intestinal uptake compared to conventional zinc sources. This approach has been applied in fortified flour and dairy-based drinks to improve dietary zinc intake. An overview of the synthesis and characterization of these nanoparticles is illustrated in Figure 1.

e-ISSN : 2682-7948

Figure 1
Graphical abstract from research by Qiang Wang et al. (2022)



Note. Retrieved from "Zinc oxide nanoparticles synthesized using coffee leaf extract assisted with ultrasound as nanocarriers for mangiferin" by Qiang Wang et al., 2022, Current Research in Food Science, 5, 868-877. Copyright 2022 Elsevier.

In terms of the physical quality of food, ZnO NPs contribute to the stabilisation of colour and texture (Souza et al., 2020). Their antioxidant properties reduce pigment oxidation, while their interaction with food macromolecules strengthens structural integrity. For example, ZnO-based coatings on fresh-cut apples can reduce enzymatic browning and maintain firmness during storage (Maringgal et al., 2020). In dairy systems, ZnO NPs provide dual functionality by enhancing microbial safety and nutritional value. They interact with milk proteins such as casein while inhibiting the growth of spoilage microorganisms. ZnO incorporation in yogurt can extend shelf life while increasing zinc content without significantly affecting taste or texture.

ZnO NPs also play an important role in Pickering emulsions, where they act as solid stabilisers at oil–water interfaces (Roy et al., 2022). By forming a robust physical barrier around droplets, they prevent coalescence and improve emulsion stability. This is useful in products such as salad dressings and sauces, where ZnO-stabilised emulsions enhance texture while providing antimicrobial and antioxidant protection. Overall, ZnO NPs exemplify how research-driven ideas can be translated into impactful, real-world applications. Their multifunctionality offers significant potential to improve food safety, quality, and nutrition, while supporting more sustainable and innovative food systems.

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BULETIN APB EDISI 16/2026
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