

Berry Bliss: A Comparative Study of the Zinc Nanoparticles Synthesized from Gooseberry, Strawberry, Blueberry, and Cranberry Extracts

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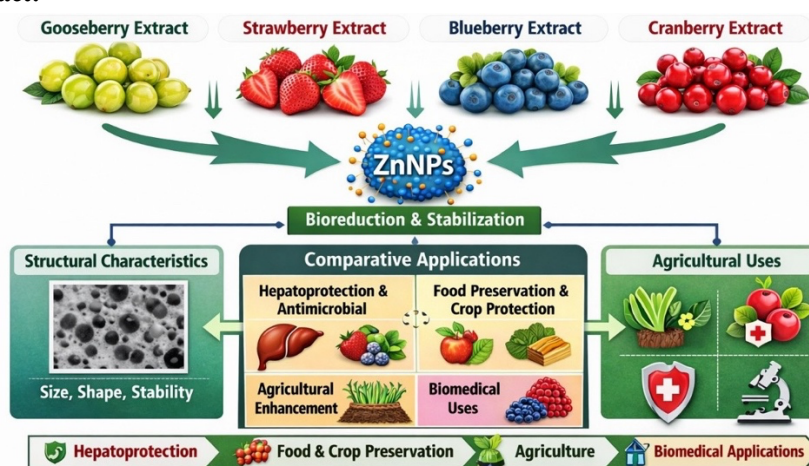
Abstract

The green synthesis of zinc nanoparticles (ZnNPs) using fruit extracts has gained significant attention as an eco-friendly and cost-effective alternative to conventional chemical and physical methods. Plant-mediated nanoparticle synthesis utilizes bioactive phytochemicals as reducing and stabilizing agents, minimizing the need for hazardous reagents while enhancing the biocompatibility of the resulting nanostructures. Gooseberry (*Physalis peruviana*), strawberry (*Fragaria ananassa*), blueberry (*Vaccinium spp.*), and cranberry (*Vaccinium macrocarpon*) extracts have been extensively explored for ZnNP synthesis due to their rich reservoirs of flavonoids, anthocyanins, phenolic acids, alkaloids, and vitamins. Comparative studies reveal that gooseberry-derived ZnNPs exhibit promising hepatoprotective, antioxidant, and antimicrobial effects, while strawberry-based ZnNPs are particularly efficient in food preservation, crop protection, and extending shelf life. Blueberry-mediated ZnNPs and nanofertilizers demonstrate notable agricultural benefits, including enhanced nutrient uptake and pathogen resistance. Conversely, cranberry extracts have shown superior potential in biomedical applications, with ZnNP composites effective against bacterial biofilms, cancer cell proliferation, and wound healing. The diverse phytochemical profiles of these fruits significantly influence nanoparticle morphology, stability, and functional properties, thereby dictating their specific applications. This chapter provides a comparative assessment of ZnNPs synthesized from gooseberry, strawberry, blueberry, and cranberry extracts, highlighting synthesis strategies, structural characteristics, and application domains. It emphasizes the role of fruit-derived biomolecules in tailoring nanoparticle functionality and suggests future prospects in agriculture, biomedicine, energy storage, and environmental management. The findings support fruit-mediated ZnNPs as a promising pathway toward sustainable nanotechnology.

Keywords: Zinc nanoparticles, Gooseberry, Strawberry, Blueberry, Cranberry, Green synthesis, Phytochemicals, Agriculture, Biomedicine, Nanotechnology applications.

How to cite this article: Awasthi S, Shahi S. Berry Bliss: A Comparative Study of the Zinc Nanoparticles Synthesized from Gooseberry, Strawberry, Blueberry, and Cranberry Extracts. *Int J Drug Deliv Technol.* 2026;16(18s): 550-557. DOI: 10.25258/ijddt.16.18s.59

Graphical Abstract:



1. Introduction

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Nanotechnology has transformed scientific and industrial innovation, providing versatile tools for addressing global challenges in healthcare, agriculture, energy, and environmental management¹. Among the many nanomaterials developed, zinc oxide nanoparticles (ZnNPs) occupy a prominent position due to their multifunctional properties, including antimicrobial activity, ultraviolet (UV) blocking, photocatalytic potential, and their role as essential micronutrients in plant systems^{2,3}. However, conventional methods of synthesizing ZnNPs often rely on toxic chemicals, high energy consumption, and complex procedures, raising environmental and biosafety concerns⁴. This has led to the growing interest in green synthesis approaches, which utilize biological resources such as plants, fungi, algae, and bacteria as reducing and capping agents. Among these, plants—especially fruits—offer several advantages, including wide availability, cost-effectiveness, and the presence of diverse phytochemicals that can reduce metal ions and stabilize nanoparticles⁵.

1.1 The Promise of Green Synthesis

Green synthesis of nanoparticles is aligned with the principles of sustainable chemistry, emphasizing environmentally benign processes, low-cost raw materials, and safe by-products¹. Unlike chemical routes that may leave hazardous residues, plant-mediated synthesis ensures that nanoparticles are coated with phytochemicals, enhancing their biocompatibility, stability, and functionality. Moreover, plant extracts act as dual agents: they reduce metal ions to their nano-form and simultaneously cap the nanoparticles, preventing aggregation⁵. The result is a simplified, single-step process that is both energy-efficient and scalable. Within the realm of plant-based synthesis, fruits stand out due to their high phytochemical density⁶. They contain natural antioxidants such as polyphenols, flavonoids, anthocyanins, tannins, and organic acids, which play a critical role in reducing zinc salts into nanoparticles. Furthermore, fruit-derived ZnNPs inherit bioactive properties from these phytochemicals, making them attractive for applications in food preservation, medicine, agriculture, and environmental remediation.

1.2 Why Berries?

Among fruits, berries hold a unique place in nanotechnology research. Berries are not only nutritionally rich but are also repositories of diverse phytochemicals^{7,8}. Their extracts provide the necessary biomolecules for ZnNP synthesis, while their health-promoting compounds synergize with the

nanoparticles to yield multifunctional outcomes^{9,10}. Gooseberry (*Physalis peruviana*), strawberry (*Fragaria ananassa*), blueberry (*Vaccinium spp.*), and cranberry (*Vaccinium macrocarpon*) have gained research attention for their role in nanoparticle biosynthesis¹¹. These four fruits share a common feature: they are rich in polyphenolic compounds that act as natural antioxidants and reducing agents. At the same time, each fruit provides a distinct phytochemical fingerprint, which influences the morphology, stability, size, and functionality of the nanoparticles produced¹². For example, gooseberry is rich in alkaloids and anolides; strawberry contains anthocyanins and ellagic acid; blueberry is a well-known source of chlorogenic acid and anthocyanins; and cranberry is rich in proanthocyanidins and flavonols. Such chemical diversity leads to nanoparticles with distinct biological activities and application profiles^{13,14}.

1.3 Zinc Nanoparticles: A Brief Overview

Zinc oxide nanoparticles (ZnNPs) are among the most widely investigated nanomaterials due to their multifunctionality³. Their antimicrobial properties make them suitable for food preservation, medical coatings, and crop protection. Their photocatalytic and UV-blocking capabilities have been exploited in textiles, cosmetics, and wastewater treatment. Additionally, zinc is an essential micronutrient in both plants and animals, and ZnNPs have been applied as nanofertilizers to improve nutrient uptake efficiency and plant growth⁴. One of the most striking advantages of ZnNPs is their low toxicity compared to other metal nanoparticles such as silver or cadmium⁵. When synthesized using green methods, ZnNPs are even more biocompatible, as the phytochemicals act as natural stabilizers. This property has opened new avenues for their use in sensitive areas such as drug delivery, wound healing, and anticancer therapies.

1.4 Phytochemical Contributions to Nanoparticle Formation

The synthesis of nanoparticles using plant extracts depends heavily on the phytochemical composition of the source material. The role of different phytochemicals can be summarized as follows:

Flavonoids and polyphenols: Function as reducing agents by donating electrons to zinc ions, converting them into ZnNPs. They also cap the nanoparticles, preventing agglomeration¹.

Anthocyanins: Provide antioxidant properties and influence the coloration and morphology of nanoparticles¹⁰.

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Organic acids (citric, malic, ascorbic acids): Contribute to reduction reactions and enhance nanoparticle stability⁶.

Alkaloids and terpenoids: Aid in nanoparticle stabilization and sometimes impart additional bioactivity^{13,14}.

Each berry's unique phytochemical profile determines the characteristics of its ZnNPs, highlighting the importance of fruit-specific studies.

1.1.1 Gooseberry (*Physalis peruviana*)

Gooseberry extracts have been used in the green synthesis of ZnNPs due to their abundance of anolides, alkaloids, and phenolic compounds^{12,13}. Studies have shown that gooseberry-mediated ZnNPs exhibit strong hepatoprotective and antimicrobial activities, making them promise for pharmaceutical and food safety applications^{14,15}. Their high phenolic content contributes to stable, spherical nanoparticles with potent bioactivity.

1.1.2 Strawberry (*Fragaria ananassa*)

Strawberries are rich in anthocyanins, ellagic acid, and flavonoids, which contribute significantly to nanoparticle synthesis^{2,6}. ZnNPs derived from strawberry extracts have demonstrated antifungal and antibacterial properties, as well as the ability to extend the shelf life of perishable foods^{7,8}. In combination with chitosan films, strawberry ZnNPs form effective food coatings that improve barrier properties and delay microbial spoilage. This highlights their dual role in food packaging and postharvest preservation^{16,17}.

1.1.3 Blueberry (*Vaccinium spp.*)

Blueberry extracts have been widely investigated for agricultural applications³. Their phytochemicals, especially anthocyanins and chlorogenic acid, enable the synthesis of nanoparticles and nanofertilizers⁴. Blueberry-mediated ZnNPs improve nutrient efficiency in crops and mitigate plant pathogens¹⁸. Additionally, ZnNP coatings on blueberries reduce postharvest losses by delaying fungal growth and maintaining fruit quality¹⁹. These findings underscore the potential of blueberry ZnNPs in sustainable agriculture.

1.1.4 Cranberry (*Vaccinium macrocarpon*)

Cranberries contain high levels of proanthocyanidins and flavanols, which not only facilitate ZnNP synthesis but also provide strong bioactivity^{12,20}. Cranberry-derived nanocomposites, such as graphene oxide–cranberry nanosheets, have been applied in wound healing and antibiofilm therapies, showing efficacy in vitro and in vivo. Cranberry-based ZnNPs also exhibit

anticancer and antimicrobial activities, making them versatile candidates for biomedical applications^{21,22}.

1.5 Comparative Importance of Berry-Derived ZnNPs

A comparative perspective shows that while all four berries enable ZnNP synthesis, their applications diverge based on phytochemical composition:

Gooseberry: Strong biomedical orientation (hepatoprotection, antimicrobial)¹⁵.

Strawberry: Dominantly agricultural (crop protection, shelf-life extension)²⁰.

Blueberry: Agriculture and nanofertilizers (plant growth, pathogen resistance)⁵.

Cranberry: Biomedical focus (antibacterial, wound healing, anticancer)²¹.

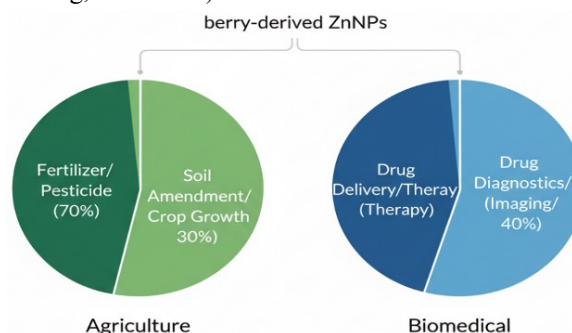


Figure 1. Comparative applications of berry-derived ZnNPs

Pie chart showing % applications of each berry category in agriculture vs. biomedical fields.

1.6 Research Gap and Rationale

Although several studies have reported the synthesis and application of ZnNPs using these berry extracts, comparative studies remain limited¹. The variability in phytochemical composition, synthesis protocols, and application domains suggests the need for a systematic comparison³. Understanding these differences can help tailor ZnNPs for specific applications, whether in food packaging, medicine, agriculture, or energy⁴. Moreover, long-term biosafety and environmental impact studies are still lacking⁵. While green synthesis reduces toxicity, the interactions of berry-derived ZnNPs with ecosystems, soil, and human health must be carefully examined. Addressing these gaps will facilitate the scaling-up and industrial application of such nanoparticles.

2. Methodology

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Figure 2. Methods for Green Synthesis of Zinc Nanoparticles from Berry Extracts

2.1 Preparation of Fruit Extracts

Fresh fruits (gooseberry, strawberry, blueberry, and cranberry) are thoroughly washed with distilled water to remove dust and surface impurities. They are then cut into small pieces and homogenized. The homogenate is filtered through Whatman No. 1 filter paper or centrifuged at 10,000 rpm for 10–15 minutes to obtain a clear aqueous extract. This extract serves as the reducing and stabilizing agent due to its rich phytochemical content (polyphenols, flavonoids, organic acids, and alkaloids).

Gooseberry extract, prepared from fresh fruit pulp, is rich in bioactive constituents such as with anolides, alkaloids, and diverse phenolic compounds, which contribute significantly to its reducing and stabilizing capability in nanoparticle synthesis^{12,15}. Strawberry extract, obtained from fresh fruits or agro-waste biomass such as seeds and peels, contains high levels of anthocyanins and ellagic acid, making it an effective and sustainable source of phytochemicals^{6,23}. Blueberry extract is typically derived from the fruit pulp and is abundant in anthocyanins and chlorogenic acid, compounds known for their strong antioxidant and metal-chelating properties⁹. Cranberry extract, extracted from fruit juice or pulp, is characterized by a high content of proanthocyanidins and flavonols, which play a crucial role in directing nanoparticle growth and stabilization¹¹.

2.2 Preparation of Zinc Precursor Solution

A 0.01–0.05 M aqueous solution of zinc acetate dihydrate [$\text{Zn}(\text{CH}_3\text{COO})_2 \cdot 2\text{H}_2\text{O}$] or zinc nitrate hexahydrate [$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$] is prepared as the metal precursor. The choice of salt depends on desired nanoparticle stability and crystallinity.

2.3 Synthesis of Zinc Nanoparticles

The fruit extract is slowly added dropwise to the zinc precursor solution under continuous stirring (500–700 rpm) at 60–80 °C. The ratio of extract to zinc solution typically ranges from 1:2 to 1:4, depending on the reducing strength of each fruit extract. The color of the

mixture gradually changes (yellowish to brownish), indicating the reduction of Zn^{2+} ions and the formation of ZnNPs.

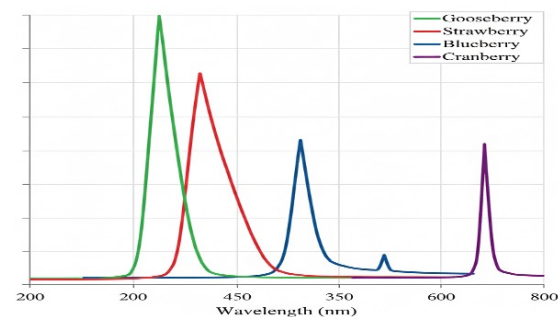
Gooseberry aqueous extract efficiently reduces Zn^{2+} ions to form predominantly spherical zinc nanoparticles with sizes ranging from 20 to 60 nm, reflecting strong reducing and capping activity of its bioactive constituents^{12,15}. Strawberry extracts, obtained from both fresh fruits and waste biomass, similarly produce quasi-spherical ZnNPs in the size range of 15–50 nm, with enhanced colloidal stability attributed to the high anthocyanin content acting as effective stabilizing agents^{16,23}. In the case of blueberry, the extract leads to the formation of zinc nanoparticles with varied morphologies, including spherical and rod-like structures measuring approximately 20–80 nm, making them particularly suitable for applications such as nanofertilizers^{3,24}. Cranberry extract, rich in proanthocyanidins, promotes the growth of nanosheet-like and crystalline ZnNPs, which are often integrated into advanced systems such as hydrogels or nanocomposites due to their distinctive structural and functional properties¹¹.

2.4 Separation and Purification

The mixture is cooled and centrifuged at 10,000–12,000 rpm for 15–20 minutes. The pellet containing ZnNPs is collected, washed 2–3 times with distilled water and ethanol to remove unreacted phytochemicals, and dried in a hot-air oven (60 °C) or lyophilized to obtain a fine nanoparticle powder.

2.5 Characterization

The synthesized ZnNPs are characterized to confirm their formation, morphology, and stability:

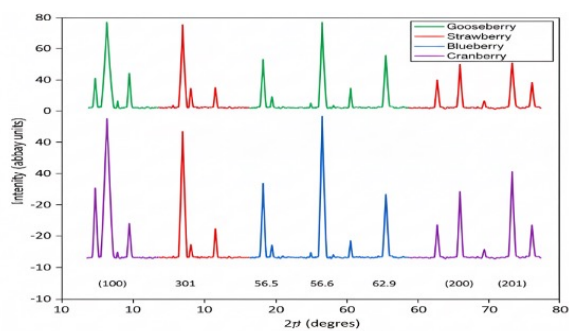


Graph 1. UV-Vis spectroscopy: Surface plasmon resonance band (typically 300–380 nm for ZnNPs). The graph shows the absorption spectra of four berries—Gooseberry, Strawberry, Blueberry, and Cranberry—across wavelengths ranging from about 200 to 800 nanometers. The horizontal axis represents wavelength (in nanometers), which corresponds to different regions of light from ultraviolet to near infrared, while the vertical axis represents the relative

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amount of light absorbed. Each berry displays a distinct absorption pattern. Gooseberry has a strong absorption peak in the ultraviolet region around 250 nm and very little absorption at longer wavelengths. Strawberry shows a prominent peak near 400 nm in the violet-blue region. Blueberry has a main peak around 350 nm and a smaller secondary peak near 550 nm. Cranberry displays a strong absorption peak around 650 nm in the red region. These differences in absorption are due to the specific pigments present in each fruit, and they help explain the fruits' visible colors, since the color we see corresponds to the wavelengths of light that are reflected rather than absorbed^{1,7,20}.

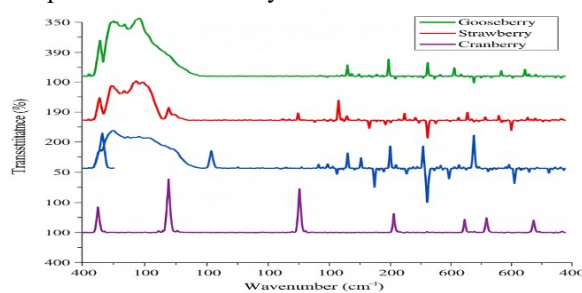
Each sharp peak corresponds to a specific crystalline structure within the sample. The position of a peak (its 2θ value) identifies the spacing between atomic planes in the material, while the height (intensity) reflects how strongly that structure diffracts X-rays. The labeled peaks—such as (100), (301), (200), and (201)—represent particular crystallographic planes. All four berries show multiple sharp peaks, indicating the presence of crystalline components rather than completely amorphous material. However, the peak positions and intensities differ among the fruits, meaning their internal structural compositions vary. For example, Gooseberry and Strawberry show strong peaks at lower angles, while Blueberry and Cranberry exhibit prominent peaks at higher angles as well. These differences reflect variations in their molecular and crystalline makeup, likely due to differences in sugars, organic acids, and other plant compounds present in each fruit.



Graph 2. XRD (X-ray diffraction): Crystallinity and phase analysis.

Each fruit displays characteristic absorption bands that reflect its chemical composition. The broad bands in the higher wavenumber region (around 3200–3500 cm^{-1}) are typically associated with O–H stretching vibrations, indicating the presence of water, alcohols, and phenolic compounds. Peaks near 2900 cm^{-1} generally correspond to C–H stretching from organic

molecules. In the mid-region (around 1600–1700 cm^{-1}), absorption bands are often linked to C=O stretching from acids, esters, or other carbonyl-containing compounds. Additional peaks between 1000 and 1200 cm^{-1} are commonly related to C–O stretching vibrations, which are typical of sugars and carbohydrates. Although the overall spectral patterns are similar—since all fruits contain similar types of organic compounds—the differences in peak positions and intensities indicate variations in their relative concentrations of sugars, acids, phenolics, and other bioactive compounds. These unique spectral “fingerprints” help distinguish the chemical composition of each berry.



Graph 3. FTIR spectroscopy: Identification of functional groups responsible for reduction and stabilization.

The figure 3 illustrates the influence of different berry fruit extracts on the morphology of green-synthesised zinc nanoparticles at the nanoscale (50 nm). Gooseberry extract produces densely packed, small, and fairly uniform spherical nanoparticles, indicating the strong reducing and stabilizing action of its phytochemicals. Strawberry extract results in comparatively larger, well-defined spherical particles, suggesting moderate control over particle growth. Blueberry extract yields a mixed population of spherical and short rod-like nanoparticles, reflecting anisotropic growth driven by its diverse polyphenols and anthocyanins²⁵. In contrast, cranberry extract forms plate-like and elongated crystalline structures, indicating strong facet-selective binding of phytochemicals that promotes directional growth. Overall, the figure highlights that variation in phytochemical composition among fruit extracts plays a decisive role in controlling the size, shape, and structural diversity of zinc nanoparticles synthesized via green routes.

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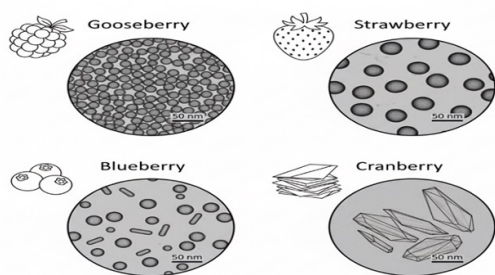


Figure 3. Comparative Morphologies of ZnNPs synthesized from different berry extracts

4. Results and Discussion

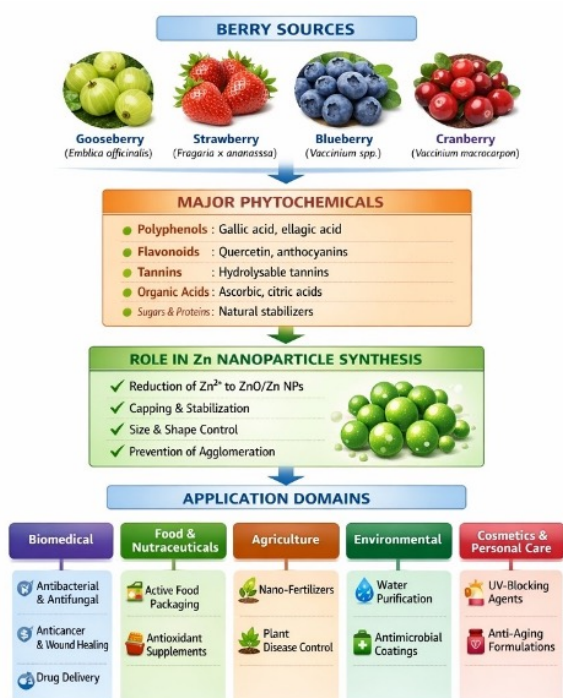


Figure 4. Schematic diagram “Berry Phytochemicals-ZnNP Application Domin”

4.1 Comparative Morphology and Stability

ZnNPs synthesized from these fruits exhibit varied morphologies. Gooseberry and strawberry typically produce spherical nanoparticles, whereas blueberry yields more diverse structures including rods and aggregates. Cranberry-derived composites form nanosheets, enhancing surface reactivity. Stability is influenced by phytochemical content, with polyphenols providing strong capping effects^{1,7,20}.

4.2 Agricultural Applications

Blueberry and strawberry-derived ZnNPs are predominantly applied in crop protection and postharvest storage. ZnNP coatings effectively delay microbial spoilage in strawberries and blueberries, extending shelf life¹⁷. Gooseberry ZnNPs have limited

agricultural application but show strong antimicrobial activity¹⁸.

4.3 Biomedical Applications

Cranberry-derived ZnNPs composites exhibit superior biomedical potential, particularly in antibiofilm wound healing and anticancer studies. Gooseberry-based ZnNPs also hold therapeutic promise against hepatic injury²⁶. Strawberries and blueberries are primarily directed toward agricultural preservation, with limited biomedical use²⁷.

4.4 Environmental and Energy Applications

Cranberry bean-derived carbon catalysts in zinc–air batteries highlight potential environmental/energy applications. Blueberry ZnNPs contribute to eco-friendly fertilizers²⁸. These findings indicate expanding roles beyond agriculture and medicine²⁹.

5. Conclusion and Future Directions

The comparative analysis reveals that gooseberry, strawberry, blueberry, and cranberry extracts serve as sustainable bio-reductants for ZnNP synthesis, each contributing distinct nanoparticle characteristics and applications. Gooseberry and cranberry extracts exhibit stronger biomedical applications, while strawberry and blueberry focus on agricultural and postharvest uses. Future research should explore:

To advance this field, future research must prioritize the standardization of synthesis protocols to ensure reproducibility, alongside rigorous toxicological studies to confirm biosafety for clinical and environmental use. Furthermore, there is significant potential in developing hybrid nanocomposites that combine multiple berry extracts to boost multifunctionality. Ultimately, focusing on industrial scale-up will be essential for translating these green-synthesized nanoparticles into viable commercial solutions for sustainable food packaging, advanced wound healing, and energy storage.

References:

1. Khan, A. U., Malik, N., Singh, B., Ansari, N. H., Rehman, M., & Yadav, A. Biosynthesis, and characterization of Zinc oxide nanoparticles (ZnONPs) obtained from the extract of waste of strawberry. *Journal of Umm Al-Qura University for Applied Sciences*, 2023, 9(3), 268-275. <https://doi.org/10.1007/s43994-023-00038-5>
2. Luksiene, Z., Rasiukeviciute, N., Zudyte, B., & Uselis, N. Innovative approach to sunlight activated biofungicides for strawberry crop protection: ZnO nanoparticles. *Journal of photochemistry and photobiology B: Biology*, 2020, 203,

Berry Bliss: A Comparative Study Of The Zinc Nanoparticles Synthesized From Gooseberry, Strawberry, Blueberry, And Cranberry Extracts

- 111656.<https://doi.org/10.1016/j.jphotobiol.2019.111656>
- Naik, J., & David, M. Phytofabrication of silver and zinc oxide nanoparticles using the fruit extract of *Phyllanthus emblica* and its potential anti-diabetic and anti-cancer activity. *Particulate Science and Technology*, 2023, 41(6), 761-773. <https://doi.org/10.1080/02726351.2022.2141668>
 - Prasad, S., Patel, B., Kumar, P., Mitra, P., & Lall, R. Cranberry: A promising natural product for animal health and performance. *Current Issues in Molecular Biology*, 2025, 47(2), 80. <https://doi.org/10.3390/cimb47020080>
 - Wu, Y., Han, T., Yang, H., Lyu, L., Li, W., & Wu, W. Known and potential health benefits and mechanisms of blueberry anthocyanins: A review. *Food Bioscience*, 2023, 55, 103050. <https://doi.org/10.1016/j.fbio.2023.103050>
 - Gao, Y., Xu, D., Ren, D., Zeng, K., & Wu, X. Green synthesis of zinc oxide nanoparticles using *Citrus sinensis* peel extract and application to strawberry preservation: A comparison study. *Lwt*, 2020, 126, 109297. <https://doi.org/10.1016/j.lwt.2020.109297>
 - Charoenwoodhipong, P., Zuelch, M. L., Keen, C. L., Hackman, R. M., & Holt, R. R. Strawberry (*Fragaria x Ananassa*) intake on human health and disease outcomes: a comprehensive literature review. *Critical reviews in food science and nutrition*, 2025, 65(25), 4884-4914. <https://doi.org/10.1080/10408398.2024.2398634>
 - Cianciosi, D., Diaz, Y. A., Qi, Z., Yang, B., Chen, G., Cassotta, M., ... & Giampieri, F. Strawberry as a health promoter: an evidence-based review. Where are we 10 years later? *Food & Function*, 2025, 16(14), 5705-5732. <https://doi.org/10.1039/D5FO01888A>
 - Duan, Y., Tarafdar, A., Chaurasia, D., Singh, A., Bhargava, P. C., Yang, J., ... & Awasthi, M. K. Blueberry fruit valorization and valuable constituents: A review. *International Journal of Food Microbiology*, 2022, 381, 109890. <https://doi.org/10.1016/j.ijfoodmicro.2022.109890>
 - Xu, J., Li, C., Wu, W., Kong, L., Xiao, L., Ma, W., & Zhang, L. Cranberry research progress: A systematic review of chemical composition, pharmacological mechanisms, clinical applications, and nutritional significance. *International Journal of Molecular Sciences*, 2025, 26(19), 9707. <https://doi.org/10.3390/ijms26199707>
 - Ouzakar, S., Senhaji, N. S., Bouziane, H., & Abrini, J. Effect of microalgae-based ZnO nanoparticles coating on postharvest quality of organically grown blueberry (*Vaccinium corymbosum*) fruit. *Food Bioscience*, 2024, 61, 104749. <https://doi.org/10.1016/j.fbio.2024.104749>
 - Yehia, H. M., Elkhadragey, M. F., Shebl, R. I., Al-Masoud, A. H., & El-Din, M. F. S. Control some foodborne pathogens, contaminated bacteria and fungi by fabrication calyx cape gooseberry (*Physalis peruviana* L.) nanoparticles. *Food Science and Technology*, 2022, 42, e116021. <https://doi.org/10.1590/fst.116021>
 - Mulyadewi, A., Mahbub, M. A. A., Irmawati, Y., Balqis, F., Adios, C. G., & Sumboja, A. Rechargeable zinc-air batteries with seawater electrolyte and cranberry bean shell-derived carbon electrocatalyst. *Energy & Fuels*, 2022, 36(10), 5475-5482. <https://doi.org/10.1021/acs.energyfuels.2c00696>
 - Zhao, T., Sun, Q., Marques, M., & Witcher, M. Anticancer properties of *Phyllanthus emblica* (Indian gooseberry). *Oxidative medicine and cellular longevity*, 2015, (1), 950890. <https://doi.org/10.1155/2015/950890>
 - Aboulthana, W. M., Omar, N. I., El-Feky, A. M., Hassan, A. K., Hasan, E. A., Seif, M., & Youssef, A. M. Phyto-and biochemical study on cape gooseberry (*Physalis peruviana* L.) extract incorporated with metal nanoparticles against hepatic injury induced in rats. *Natural Product Research*, 2024, 1-14. <https://doi.org/10.1080/14786419.2024.2358392>
 - Shantharaj, D., Naranjo, E., Merfa, M. V., Cobine, P. A., Santra, S., & De La Fuente, L. Zinc oxide-based nanoformulation zinkicide mitigates the xylem-limited pathogen *Xylella fastidiosa* in tobacco and southern highbush blueberry. *Plant Disease*, 2023, 107(4), 1096-1106. <https://doi.org/10.1094/PDIS-01-22-0246-RE>
 - Tamizhdurai, P., Albakri, G. S., Khalid, M., Alreshidi, M. A., & Yadav, K. K. Bio fabricated palladium nano particles using phytochemicals from aqueous cranberry fruit extract for anti-

Berry Bliss: A Comparative Study Of The Zinc Nanoparticles Synthesized From Gooseberry, Strawberry, Blueberry, And Cranberry Extracts

- bacterial, cytotoxic activities and photocatalytic degradation of anionic dyes. *RSC advances*, 2024, 14(33), 23730-23743. DOI: [10.1039/D4RA03177F](https://doi.org/10.1039/D4RA03177F)
18. Saravanan, K., & Kathirvel, P. Fabrication of ZnO nanoparticles reinforced PHB/PEG nanocomposite film for active packaging of Indian gooseberry and bread. *Polymer Bulletin*, 2025, 82(15), 10415-10451. <https://doi.org/10.1007/s00289-025-05945-7>
19. Singh, L., Sadawarti, R. K., Singh, S. K., Rajput, V. D., Minkina, T., & Sushkova, S. Efficacy of nano-zinc oxide and iron oxide formulations on shelf life of strawberry. *Eurasian Journal of Soil Science*, 2024, 13(3), 254-262. <https://doi.org/10.18393/ejss.1484756>
20. Elhabal, S. F., Al-Zuhairy, S. A., El-Nabarawi, M., Mohamed Elrefai, M. F., Shoela, M. S., Hababeh, S., ... & Amin, A. Enhancing Photothermal Therapy for Antibiofilm Wound Healing: Insights from Graphene Oxide-Cranberry Nanosheet Loaded Hydrogel in vitro, in silico, and in vivo Evaluation. *International Journal of Nanomedicine*, 2024, 12999-13027. <https://doi.org/10.2147/IJN.S482836>
21. Elhabal, S. F., Al-Zuhairy, S. A., El-Nabarawi, M., Mohamed Elrefai, M. F., Shoela, M. S., Hababeh, S., ... & Amin, A. Enhancing Photothermal Therapy for Antibiofilm Wound Healing: Insights from Graphene Oxide-Cranberry Nanosheet Loaded Hydrogel in vitro, in silico, and in vivo Evaluation. *International Journal of Nanomedicine*, 2024, 12999-13027. <https://doi.org/10.2147/IJN.S482836>
22. Nemzer, B. V., Al-Taher, F., Yashin, A., Revelsky, I., & Yashin, Y. Cranberry: chemical composition, antioxidant activity and impact on human health: overview. *Molecules*, 2022, 27(5), 1503.
23. Kumar, G., Madka, V., Pathuri, G., Ganta, V., & Rao, C. V. Molecular mechanisms of cancer prevention by gooseberry (*Phyllanthus emblica*). *Nutrition and cancer*, 2022, 74 (7), 2291-2302. <https://doi.org/10.1080/01635581.2021.2008988>
24. Balderas-León, I., Silva-Jara, J. M., López-Álvarez, M. Á., Ortega-Gudiño, P., Mendoza-Galván, A., Fabela-Sánchez, O., ... & Macías-Rodríguez, M. E. Nanoflower-Shaped ZnO Nanoparticles Reduced with Blueberry Waste and Their Evaluation of Malachite Green Dye Degradation. *Ceramics*, 2025, 8(1), 19. <https://doi.org/10.3390/ceramics8010019>
25. Murgueitio-Herrera, E., Falconí, C. E., Cumbal, L., Gómez, J., Yanchatipán, K., Tapia, A., ... & Toulkeridis, T. Synthesis of iron, zinc, and manganese nanofertilizers, using Andean blueberry extract, and their effect in the growth of cabbage and lupin plants. *Nanomaterials*, 2022, 12(11), 1921. <https://doi.org/10.3390/nano12111921>
26. Parvinroo, S., Habibi Yengjeh, A., Mohammadi Arvanagh, F., & Bayrami, M. Histopathological effects of zinc oxide nanoparticles prepared by *Vaccinium arctostaphylos* ethanolic fruit extract on liver and pancreas of diabetic rats. *Scientific Journal of Kurdistan University of Medical Sciences*, 2021, 26(2), 12-24. [10.52547/sjku.26.2.12](https://doi.org/10.52547/sjku.26.2.12)
27. Puišo, J., Jonkuvienė, D., Mačionienė, I., Šalomskienė, J., Jasutienė, I., & Kondrotas, R. Biosynthesis of silver nanoparticles using lingonberry and cranberry juices and their antimicrobial activity. *Colloids and Surfaces B: Biointerfaces*, 2014, 121, 214-221. <https://doi.org/10.1016/j.colsurfb.2014.05.001>
28. Regni, L., Del Buono, D., Micheli, M., Facchin, S. L., Cesarini, A., Priolo, D., & Proietti, P. Biogenic zinc oxide nanoparticles improve in vitro growth of blueberries. *Horticulturae*, 2024, 10(12), 1234. <https://doi.org/10.3390/horticulturae10121234>
29. Sani, A., Hassan, D., Ehsan, M., Sánchez-Rodríguez, E. P., & Melo-Máximo, D. V. Improving Strawberry Shelf Life Using Chitosan and Zinc Oxide Nanoparticles from Ginger-Garlic Extracts. *Applied Food Research*, 2025, 100765. <https://doi.org/10.1016/j.afres.2025.100765>