ISSN: 2694-1708
Insights in Chemistry and Biochemistry
DOI: 10.33552/ICBC.2023.02.000550
Iris Publishers

Review Article

Pioneering Nanotechnology in the Landscape of Food Science

Mohan Kumar[1], Madhuri Chaurasia[2] and Sulekh Chandra[2]*

[1]*Department of Chemistry, Shri Varshney College, Raja Mahendra Pratap Singh State University, Aligarh, Uttar Pradesh, India*

[2]*Department of Chemistry, Zakir Husain Delhi College, University of Delhi, New Delhi, India*

Corresponding author: Sulekh Chandra, Department of Chemistry, Zakir Husain Delhi College, University of Delhi, New Delhi, India.

Received Date: December 04, 2023

Published Date: December 13, 2023

Abstract

In the domains of food, medicine, and agriculture, nanotechnology emerges as a crucial and transformative technology with the potential to significantly advance the development and sustainability of these sectors, exerting a positive influence on their trajectory. Within the realm of food science and food microbiology, there has been a growing reliance on the application of nanoparticles, spanning areas such as food processing, packaging, the creation of functional foods, and ensuring food safety. This integration of nanotechnological interventions has led to food products boasting extended shelf lives, reduced contamination levels, and enhanced overall quality. Furthermore, nanostructures not only augment bioavailability but also improve the solubility of ingredients in vivo, facilitating targeted release at specific locations. Additionally, these nanostructures play diverse roles, serving as carriers for nutraceuticals, nano-additives, and anticaking agents. Despite the myriad benefits associated with nanotechnology, there is a mounting concern regarding its application, primarily due to apprehensions about the potential accumulation of nanomaterials in both the environment and the human body, posing conceivable health and safety risks. This study aims to provide a foundational understanding of the diverse applications of nanotechnology in the realm of food and to undertake a comprehensive evaluation of the potential advantages and hazards associated with the future use of nanoscale materials, with a commitment to originality and academic integrity.

Keywords: Nanomaterials; Functional food; Food processing; Pathogens

Introduction

Nanotechnology, characterized by its inventive manipulation of nanomaterials, plays a crucial role in the food and agricultural sectors [1,2]. Operating within the scale of 1-100 nanometers, nanotechnology enables the production and utilization of materials with distinctive atomic, molecular, or macromolecular properties. Its innovative practices contribute to advancements in crop enhancement, food quality, and human health [3]. Diverging from macroscale counterparts, these materials possess unique physiochemical properties, including high surface-to-volume ratios, and novel characteristics such as optical, color, solubility, toxicity, magnetic attributes, strength, diffusivity, and thermodynamic properties [4]. Industries spanning food, medicine, and agriculture leverage nanotechnology to devise and implement novel systems, materials, and structures [5]. Transforming food science and technology, nanotechnology unlocks various possibilities, benefiting the food industry with applications that enhance taste, flavor, color, texture, food durability, bioactive material absorption capacity, and a broad spectrum of nutraceuticals [6]. Nano-sensors monitor health hazards, and food packaging materials exhibit enhanced mechanical strength. The nanotechnology market in the food sector has reached an approximate value of 8.5 billion USD, predominantly directed toward packaging, health-related products, and beverages [7]. Prominent global food corporations invest significantly in research and development, exploring the integration of nanotechnology into meat, fish, dairy, vegetables, and bakery products. In the food industry, nanotechnology enhances quality and safety, fortifies food, improves sensory perception, extends shelf life, and facilitates the creation of antimicrobial food packaging [8, 9]. Nano-food ingredients find applications in food processing and packaging, functioning as anti-caking agents, antibacterial agents, nano additives, nanocarriers, and nanocomposites [10,11]. Nanostructures serve as nano-sensors to monitor food quality, and there is a growing inclination toward employing nano-polymers to replace traditional materials in food packaging. Nanotechnology advancements enable the creation of novel, functional meals and the targeted delivery of nutrients and bioactive substances in functional foods [12,13]. While nanotechnology proves invaluable in the food industry, the use of nanomaterials occasionally sparks debate due to scientific ambiguity and potential long-term health and environmental concerns [14]. Addressing these concerns promptly is crucial for gaining a deeper understanding of how nanomaterials and nanostructures are employed in food, focusing on enhancing their biocompatibility, safety, and toxicity. A comprehensive exploration of the physiochemical and biological characteristics of nanomaterials is essential to unravel the complexity and limitations of nanotechnology, as depicted in Figure 1, showcasing various significant applications in the field of food science (Figure 1).

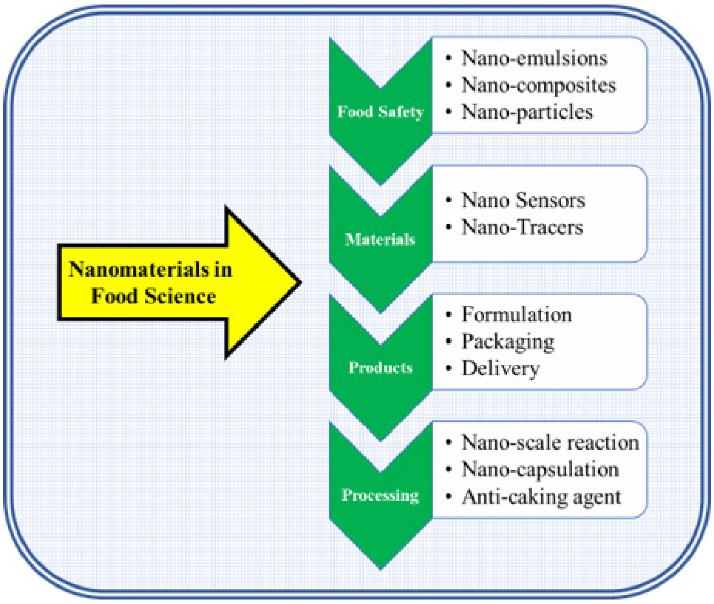

Figure 1: Various Applications of nano-materials in the field of food science.

It is possible to categorize the applications of nanotechnology in the food industry into two primary categories: food nanostructured ingredients and food nano-sensing. In this article, we have demonstrated that nanoparticles are used in the food industry and that they present several health risks to humans. We also review the regulatory and safety issues relating to these nanoparticles.

Applications of Nanomaterials in the Food Sector

Food Packaging

Nanotechnology has revolutionized food packaging, addressing critical issues such as shelf life extension and safety. Nanotechnology-based "smart" and "active" food packaging offers distinct advantages compared to conventional packaging methods. It provides superior packaging materials with enhanced mechanical strength, barrier properties, and antimicrobial features, along with nano-sensing capabilities for pathogen detection and consumer awareness of food safety status [15, 16]. Nano polymers are now employed as an alternative to traditional packaging materials, marking a notable shift in food packaging practices. The recent surge in active and intelligent packaging technologies, particularly for contamination-prone food items, has been noteworthy.

Nano-sensors play a pivotal role in detecting food deterioration and contamination, identifying toxins, pesticides, and microbial contamination through changes in taste and color [17]. Antimicrobial packaging incorporates organic substances such as bacteriocins, organic acids, and essential oils known for their antimicrobial properties, enhancing their application in polymeric materials [18]. The term "active packaging" now encompasses packaging that alters the state of food, improving sensory quality and safety, maintaining food quality for an extended shelf life, and preserving overall food quality [19]. Addressing the oxidation and de-carbonation concerns in carbonated beverages, packaging strategies focus on inhibiting the flow of oxygen and carbon dioxide (CO2), often achieved through nanocomposites, including polymers [20]. Incorporating nano-biocomposites into food packaging has significantly enhanced the gas barrier properties of these materials.

However, concerns persist regarding the potential ingestion of nano-compounds through food consumption [21]. To address environmental and health issues, comprehensive research into the toxicity and immunogenicity of nanoparticles, as well as their migration within the body, is essential. Researchers worldwide are actively seeking environmentally friendly and biodegradable nanomaterials to address this crucial aspect. Additionally, nanotechnology contributes to the development of sustainable packaging solutions, reducing environmental impact through the creation of biodegradable and eco-friendly materials.

Food Processing

In the realm of food processing, nanotechnology plays a transformative role in enhancing efficiency and product quality. Nanoemulsions and nanocapsules are employed to encapsulate and deliver bioactive compounds, enhancing their solubility and stability during processing. The term "nanofood" refers to food produced through the application of nanotechnology in various aspects of food processing, production, safety, and packaging [2]. Nanotechnology also holds the promise of extending the shelf life of numerous food products, thus mitigating food waste resulting from microbial infestation [22]. Significant potential lies in the application of nanotechnology for post-harvest food preparation [23]. Beyond its impact on particle size, size distribution, taste, consistency, and bioavailability of food, nanotechnology can also influence particle size, surface charge, and mitigate undesirable odors and flavors. Through the utilization of nanotechnology, various products such as encapsulants, emulsions, biopolymer matrices, simple solutions, and association colloids can be developed, providing the mentioned properties along with effective delivery methods.

Nanotechnology facilitates the creation of nano-sensors capable of detecting pollutants, mycotoxins, and microbial contamination in food [24]. The use of nanoscale filters allows for the removal of bacteria from water or milk without the need for boiling [25]. Research has demonstrated that bionanoencapsulated quercetin can effectively extend the shelf life of tomatoes, indicating the potential for similar strategies to be employed in preserving other fruits and vegetables. Nanocarriers have become a pivotal technology for delivering food additives without compromising the fundamental structure of food items [26]. An intriguing aspect of nanotechnology is its comprehensive impact on the mentioned factors, significantly transforming food products to offer unique properties.

Enhancement of Physical Properties, and Preservation of Nutrition

Nanotechnology presents a diverse range of solutions to enhance both the quality and flavor of food [27]. The widespread adoption of nanoencapsulation techniques has proven effective in improving taste release and retention while achieving culinary balance. This technology is commonly utilized for encapsulating anthocyanin pigments, known for their instability and reactivity [28]. Nano-emulsions, particularly valuable for assembling lipid-soluble bioactive chemicals, enhance both bioavailability and water dispersibility. In modern culinary applications, nanoparticle-coated capsules find application in delivering medications, vitamins, micronutrients, and microbubbles [29]. Historically, metallic oxides like silicon dioxide ($SiO2$) and titanium dioxide ($TiO2$) have been used in culinary preparations as colorings or flow agents. Notably, silicon dioxide ($SiO2$) stands out as one of the most popular nanomaterials for delivering tastes or scents in food items [30]. The encapsulation of bioactive compounds, especially those sensitive to acidic environments, not only provides resilience against adverse conditions but also facilitates the assimilation of these compounds into food products. This is particularly crucial given the low water solubility of these compounds in their non-encapsulated form [31].

Three key methods—nanocomposite, nano-emulsification, and nanostructure—are employed to encapsulate substances in minute forms, enhancing the efficient delivery of nutrients such as proteins and antioxidants for better health benefits. Polymeric nanoparticles, in particular, have demonstrated significant effectiveness in encapsulating and delivering bioactive substances such as flavonoids and vitamins [32]. The application of nanotechnology in this context not only meets consumer expectations for healthier options but also contributes to reducing food waste by maintaining the nutritional integrity of products over extended periods.

Nanomaterials and Devices in Food Safety

Ensuring food safety is a critical aspect of the food industry, and nanotechnology provides innovative solutions in this regard. Nanosensors are designed to detect contaminants and pathogens with high sensitivity and specificity, offering rapid and accurate results. These nanosensors can be integrated into various stages of the food supply chain, from production to distribution, enabling real-time monitoring and quick response to potential safety threats. The extended shelf life of functional foods is achieved through the process of nanoencapsulation of bioactive components. This method either slows down degradation processes or halts degradation until the product reaches its intended destination [33]. The harsh environment often leads to the degradation and eventual inactivation of bioactive components. Edible nano-coatings not only act as barriers to humidity and gas exchange but can also convey tastes, colors, enzymes, antioxidants, and anti-browning agents, thereby extending the shelf life of prepared meals even after opening the packaging. Diverse nanomaterials and nanodevices, such as polymeric nanoparticles, liposomal nanovesicles, nano-loaded emulsions, and temperature-time indicators, are currently employed to extend food shelf life, ensure freshness, and detect contamination in food items from heavy metals, chemicals, and allergens [34]. By manipulating the characteristics of the interfacial layer around functional components, it is often possible to decelerate chemical breakdown processes. The recently developed radio frequency identification technology (RFID) holds significant potential for various processes in food engineering and supply chain management, thanks to its speed and effectiveness [35]. Utilizing RFID technology to identify the source of contaminants in different food products could potentially enhance food safety and security. The implementation of nanotechnology in diagnostics contributes to the overall safety and quality assurance in the food supply chain. Rapid and reliable detection of contaminants ensures that potential risks are identified early in the production process, preventing the distribution of unsafe products to consumers.

Application in Diagnostic

The application of nanotechnology in diagnostics within the food industry is a testament to its versatility and precision. Nanoscale biosensors have been developed for the detection of foodborne pathogens and contaminants. These biosensors offer high sensitivity, allowing for the identification of minute amounts of harmful substances in food products. Recent progress in nano-sensors has garnered widespread attention in the food industry due to their swift detection capabilities, cost-effectiveness, and reliability [36]. These devices exhibit exceptional optical and electric properties, comprising various nanomaterials such as carbon nanotubes, nanofibers, nanorods, nanofilms, and quantum dots [37]. In response to the need for detecting deteriorating food and foodborne pathogens, a range of biosensors has been developed. A nano-biosensing technique known as surface-enhanced Raman scattering (SERS) allows for quickly and precisely identifying microbial infections [38]. Microfluidic sensors, leveraging microfluidics and liposomes, can detect harmful chemicals in aqueous samples even at low concentrations. Nano-sensors extend beyond detecting changes in humidity, temperature, microbial contamination, and item deterioration; they can also assess the condition of stored items. Identification of aflatoxin B1 has been facilitated by using gold nanoparticles and anti-aflatoxin antibodies [39]. Gold nanoparticle-activated enzyme-linked immunosorbent assays and immune-chromatographic methods have been utilized to detect botulinum neurotoxins type B and brevetoxins in processed foods [40]. Nano barcodes, employing DNA molecular beacons labeled with colored probes, offer a means to identify food pathogens [41].

Magnetic iron oxide nanoparticles have been demonstrated to isolate DNA from milk-pathogenic bacteria such as Listeria monocytogenes. Direct detection of E. coli in food samples has been achieved through the measurement and analysis of light dispersed by cells, utilizing a bacteria-laden silicon chip that binds with recognized proteins [42]. Carbon nanotube-based biosensors have gained interest due to their rapid detection, user-friendliness, and affordability, effectively identifying microbes, poisons, and degradation products in food and beverages. Silicon-based materials in nano-sensors, such as nanocantilevers, are commonly used to detect pathogens vibrating at varying frequencies [43]. Colorimetric and fluorometric nano-sensors, in combination with gold nanoparticles, have been employed to detect organophosphorus pesticides and carbamate pesticides [44]. Potentiometer sensors, developed using silica nanocomposites and multi-walled carbon nanotubes, can detect dangerous cadmium ions [45]. A novel method for detecting food dyes, including tartrazine, sunset yellow, and Sudan-I, is based on the use of multi-walled carbon nanotubes in ionic-liquid nanocomposites [46]. Researchers have introduced an electrochemical sensing technology using graphene oxide-gold nanoparticles to identify the dangerous bacteria Cronobacter sakazakii.

Safety Concerns, and Regulatory

While the potential benefits of nanotechnology in food science are substantial, addressing safety concerns and establishing robust regulatory frameworks is paramount. As nanomaterials are engineered to interact at the molecular level, questions about their potential toxicity and long-term effects on human health and the environment have been raised. Safety concerns associated with nanotechnology in food are actively investigated through comprehensive risk assessments. Researchers are studying the bioavailability and bioaccumulation of nanoparticles to understand their behavior in biological systems. Additionally, efforts are underway to develop standardized testing methods to evaluate the safety of nanomaterials used in food products. The utilization of various nanomaterials in the food industry is well-recognized for its numerous benefits, but it also introduces substantial risks to human health, the environment, and other organisms due to its cytotoxic effects [47]. Recent studies have concentrated on the potential migration of nanoparticles from packaging materials into food, investigating their impact on consumer health [48]. Despite nanoparticles typically lacking harmful components, questions have arisen about their use due to their minute size and subcellular interactions with cells. Moreover, their diminutive size elevates the risk of bioaccumulation in bodily tissues and organs [49]. For example, nanomaterials employed as anti-caking treatments have been associated with cytotoxicity in mammalian lung cells. Research indicates that carbon nanotubes, both single-walled and multi-walled, can induce oxidative stress and fibrosis in the lungs of mice and rats [50]. Contemporary food products undeniably incorporate various nanoparticles, posing a direct susceptibility of the digestive system to these nanomaterials on a daily basis [51]. Ingesting nanoparticles raises significant health concerns, as they traverse from the mouth to the stomach and eventually to the intestines [52]. Despite the progress in nanotechnology, the specific challenges that must be addressed for the emergence of a sustainable and nutritious food economy remain unclear. Consumers need to be informed about potential concerns related to nanoparticles in the environment and human health when employed in the food sector. No standardized regulatory measures addressing the use of nano-formulated products in the food and agriculture sector have been established, despite their known harm to both plants and animals. There is a pressing need for effective rules and regulations to ensure the safe application of nanoparticles in the food industry. Authorities in the European Union have emphasized that food components utilizing nanotechnology must undergo safety checks before approval for human use [53]. Despite being leading producers of nanomaterials, Japan and China currently lack adequate laws and regulations [54]. Regulatory agencies must establish criteria for commercial goods to verify quality, safety, and compliance with environmental laws for nanotechnological applications to be legal. A comprehensive international regulatory framework is imperative for effectively controlling nanoparticle use in the food industry. Collaboration between scientific communities, industry stakeholders, and regulatory agencies is crucial to establishing a comprehensive and transparent regulatory framework that balances innovation with safety.

Implications, and Future Directions

The processes involved in food processing, packaging, and long-term storage are critical factors in ensuring the production of high-quality food. The food industry has been significantly influenced by nanotechnology, which has the capability not only to enhance the flavor and texture of food but also to elevate its overall quality. Nanomaterials play a crucial role in extending the shelf life of food by safeguarding it from lipids, gases, and moisture. Additionally, these materials offer superior delivery mechanisms for bioactive chemicals, contributing to an enhanced nutritional profile. The utilization of nanomaterials and nano-sensors for detecting pathogens in food enhances consumer awareness regarding the nutritional quality of the food they consume. Moreover, nanomaterials demonstrate efficacy as food preservation agents, preventing the infiltration of moisture, lipids, gases, and undesirable flavors. It is important to note that the use of nanoparticles as food additives presents more significant hazards than their incorporation into food packaging. The production and application of nanomaterials introduce them into the food chain through air, water, and soil, potentially causing DNA damage, membrane disruption, and cell death. Despite ongoing advancements in nanobiotechnology, challenges persist. Addressing the risks associated with the use of nanostructures and nanotechnologies in the food industry necessitates a focused consideration of environmental impacts and safety concerns in research. Prioritizing safety awareness and understanding environmental consequences is crucial for the responsible growth of nanoscience in food systems. Mandatory testing of nano-foods before market release becomes imperative. In essence, although nanotechnology is a relatively recent field, its revolutionary impact on the food industry is evident, driven by cutting-edge nanotechnology and nanodevices. The future of nanotechnology in the food industry holds vast possibilities, showcasing its promising potential. As the field evolves, interdisciplinary collaboration will be key to unlocking the full potential of nanotechnology in food science. Collaboration between scientists, engineers, regulatory bodies, and industry stakeholders will facilitate the development of safe, sustainable, and innovative solutions. The future of pioneering nanotechnology in food science is characterized by a continued commitment to addressing global challenges, ensuring food security, and meeting the evolving expectations of consumers in an ever-changing world.

Conflict of Interest

The author has no conflict of interest.

Author Contributions

Dr. Madhuri Chaurasia and Dr. Mohan Kumar contributed equally to this work. The authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Acknowledgments

The author gratefully acknowledges the Department of Chemistry, Shri Varshney College, Aligarh, Uttar Pradesh, India for providing a research platform.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects.

References

1. Pushparaj K, Liu WC, Meyyazhagan A, Orlacchio A, Pappusamy M, et al. (2022) Nano-from nature to nurture: A comprehensive review on facets trends perspectives and sustainability of nanotechnology in the food sector Energy 240: 122732.
2. Neme K, Nafady A, Uddin S, Tola YB (2021) Application of nanotechnology in agriculture postharvest loss reduction and food processing: Food security implication and challenges Heliyon 7(12): e08539.
3. Fadiji AE, Mthiyane DMN, Onwudiwe DC, Babalola OO (2022) Harnessing the known and unknown impact of nanotechnology on enhancing food security and reducing postharvest losses: Constraints and future prospects Agronomy 12(7) 1657.
4. Parimala B, Dinesha BL, Vijayakumar SH, Manjunath B (2021) A review on application of nano-technology in food industry: Nano-encapsulation nano-sensors and nano-emulsions.
5. Rajput VD, Singh A, Minkina T, Rawat S, Mandzhieva S, et al. (2021) Nano-Enabled Products: Challenges and Opportunities for Sustainable Agriculture Plants 10(12): 2727.
6. Naskar A, Roy SR, Chakraborty I, Bhattacharya T (2022) Advancement of Nanotechnology in Developing Functional Foods: Nanotechnology in Functional Foods Nanotechnology in Functional Foods 1-24.
7. Babu PJ, Tingirikari JMR (2022) A review on polymeric nanomaterials intervention in food industry Polymer Bulletin 1-28.
8. Sharma A, Nagarajan J, Gopalakrishnan K, Bodana V, Singh A, et al. (2023) Nanotechnology applications and implications in food industry In Nanotechnology Applications for Food Safety and Quality Monitoring (pp 171-182) Academic Press.
9. Biswas R, Alam M, Sarkar A, Haque MI, Hasan MM, et al. (2022) Application of nanotechnology in food: processing preservation packaging and safety assessment Heliyon e11795.
10. Prasad RD, Sahoo AK, Shrivastav OP, Charmode N, Kamat R, et al. (2022) A Review on Aspects of Nanotechnology in Food Science and Animal Nutrition ES Food & Agroforestry 8: 12-46.
11. Thirumalai A, Harini K, Pallavi P, Gowtham P, Girigoswami K, et al. (2022) Nanotechnology driven improvement of smart food packaging Materials Research Innovations: 1-10.
12. Pérez H, Vargas G, Silva R (2022) Use of Nanotechnology to Mitigate Biofouling in Stainless Steel Devices Used in Food Processing Healthcare and Marine Environments Toxics 10(1): 35.
13. Ranjha M, Shafique B, Rehman A, Mehmood A, Ali A, et al. (2022) Biocompatible nanomaterials in food science technology and nutrient drug delivery: Recent developments and applications Frontiers in Nutrition 1141.
14. Mahato DK, Mishra AK, Kumar P (2021) Nanoencapsulation for agri-food applications and associated health and environmental concerns Frontiers in Nutrition 8: 663229.
15. He Y, Li H, Fei X, Peng L (2021) Carboxymethyl cellulose/cellulose nanocrystals immobilized silver nanoparticles as an effective coating to improve barrier and antibacterial properties of paper for food packaging applications Carbohydrate polymers 252: 117156.
16. Ahmed HM, Roy A, Wahab M, Ahmed M, Othman-Qadir G, et al. (2021) Applications of nanomaterials in agrifood and pharmaceutical industry Journal of Nanomaterials: 2021.
17. Thakur C, Kaushal M, Vaidya D, Verma AK, Gupta A (2022) Nanotechnology Based Specific and Sensitive Sensors for Food Pesticides Pathogen and Microbes Advanced Innovative Technologies in Agricultural Engineering for Sustainable Agriculture: 3.

18. Soltani S, Biron E, Ben Said L, Subirade M Fliss I (2022) Bacteriocin-Based Synergetic Consortia: a Promising Strategy to Enhance Antimicrobial Activity and Broaden the Spectrum of Inhibition Microbiology spectrum 10(1): e00406-21

19. Barone AS, Matheus JR, V de Souza TS, P Moreira RFA, Fai AEC (2021) Green-based active packaging: Opportunities beyond COVID-19 food applications and perspectives in circular economy—A brief review Comprehensive reviews in food science and food safety 20(5) 4881-4905.

20. Norizan MN, Abdullah N, Halim NA, Demon SZN, Mohamad IS (2022) Heterojunctions of rGO/metal oxide nanocomposites as promising gas-sensing materials—A review Nanomaterials 12(13): 2278.

21. Bajpai VK, Kamle M, Shukla S, Mahato DK, Chandra P, et al. (2018) Prospects of using nanotechnology for food preservation safety and security Journal of food and drug analysis 26(4): 1201-1214.

22. Adetunji CO, Anani OA, Olaniyan OT, Inobeme A, Bodunrinde RE, et al. (2022) Prospect of Utilizing Novel Nanomaterials for Effective Food Security Safety Packaging and Preservation In The Science of Nanomaterials (pp 273-302) Apple Academic Press.

23. Haris M Hussain T, Mohamed HI Khan A, Ansari MS Tauseef A, Akhtar N (2022) Nanotechnology–A new frontier of nano-farming in agricultural and food production and its development Science of The Total Environment 159639.

24. Ranjan A, Arora J, Chauhan A, Kumari A, Rajput VD, et al. (2022) Applications and Implications of Nanoparticles in Food Industries In The Role of Nanoparticles in Plant Nutrition under Soil Pollution (pp 223-243) Springer Cham.

25. Sarkar S, Dey JK (2021) Nanotechnology: An Insight for Food Processing Biotica Research Today 3(5): 364-366.

26. Navarro-Partida J, Castro-Castaneda CR, Santa Cruz-Pavlovich FJ, Aceves-Franco LA, Guy TO Santos A (2021) Lipid-based nanocarriers as topical drug delivery systems for intraocular diseases Pharmaceutics 13(5): 678.

27. Sun R, Lu J, Nolden A (2021) Nanostructured foods for improved sensory attributes Trends in Food Science & Technology 108: 281-286.

28. Rosales TKO, Fabi JP (2022) Nanoencapsulated anthocyanin as a functional ingredient: Technological application and future perspectives Colloids and Surfaces B: Biointerfaces: 112707

29. Kumari A, Chauhan AK (2021) Iron nanoparticles as a promising compound for food fortification in iron deficiency anemia: a review Journal of Food Science and Technology :1-17

30. Rizi KS, Rezayi M, Aryan E, Meshkat Z, Mobarhan MG (2022) Nanotechnology Applications in Food and Nutrition Science Nanomaterials and Nanotechnology in Medicine: 185-223

31. Yuan Y, Ma M, Xu Y, Wang D (2021) Surface coating of zein nanoparticles to improve the application of bioactive compounds: A review Trends in Food Science & Technology.

32. Wang X, Fan Y, Yan J, Yang M (2022) Engineering polyphenol-based polymeric nanoparticles for drug delivery and bioimaging Chemical Engineering Journal: 135661

33. Pateiro M, Gómez B, Munekata PE, Barba FJ, Putnik P, et al. (2021) Nanoencapsulation of promising bioactive compounds to improve their absorption stability functionality and the appearance of the final food products Molecules 26(6): 1547.

34. Sridhar A, Ponnuchamy M, Kumar PS, Kapoor A (2021) Food preservation techniques and nanotechnology for increased shelf life of fruits vegetables beverages and spices: a review Environmental Chemistry Letters 19(2): 1715-1735.

35. Sudarshan B, Shantanu BS, Srivaths S, Neethu S, Manjunatha C (2022) Recent Advances in Nanomaterials Used for RFID Technology and Their Applications ECS Transactions 107(1): 12189.

36. Akgönüllü S, Denizli A (2022) Nano-sensors and nano-devices for biological disaster monitoring (virus/disease epidemics/animal plagues detections) In Nanotechnology-Based Smart Remote Sensing Networks for Disaster Prevention (pp 43-57) Elsevier.

37. Moradi O (2022) A review on nanomaterial-based electrochemical sensors for determination of vanillin in food samples Food and Chemical Toxicology: 113391.

38. Zhang X, Shi Y, Chen G, Wu D, Wu Y, Li G (2022) CRISPR/Cas Systems-Inspired Nano/Biosensors for Detecting Infectious Viruses and Pathogenic Bacteria Small Methods 6(10): 2200794.

39. Girigoswami A, Ghosh MM, Pallavi P, Ramesh S, Girigoswami K (2021) Nanotechnology in Detection of Food Toxins–Focus on the Dairy Products Biointerface Res Appl Chem 11(6): 14155-72

40. Tavker N, Sharma M (2022) Nanosensors for intelligent food packaging In Nanosensors for Smart Agriculture (pp 737-756) Elsevier.

41. Ningthoujam R, Jena B, Pattanayak S, Dash S, Panda MK, et al. (2022) Nanotechnology in food science In Bio-Nano Interface (pp 59-73) Springer Singapore.

42. Wilson D, Materon EM, Ibanez-Redin G, Faria R C, Correa DS, et al. (2019) Electrical detection of pathogenic bacteria in food samples using information visualization methods with a sensor based on magnetic nanoparticles functionalized with antimicrobial peptides Talanta 194: 611-618.

43. Jafarizadeh-Malmiri H, Sayyar Z, Anarjan N, Berenjian A (2019) Nano-Sensors in food nanobiotechnology In Nanobiotechnology in food: concepts applications and perspectives (pp 81-94) Springer Cham.

44. Wang W, Wang X, Cheng N, Luo Y, Lin Y, et al. (2020) Recent advances in nanomaterials-based electrochemical (bio) sensors for pesticides detection TrAC Trends in Analytical Chemistry 132: 116041.

45. Wu W, Jia M, Zhang Z, Chen X, Zhang Q, et al. (2019) Sensitive selective and simultaneous electrochemical detection of multiple heavy metals in environment and food using a lowcost Fe3O4 nanoparticles/ fluorinated multi-walled carbon nanotubes sensor Ecotoxicology and Environmental Safety 175: 243-250.

46. Ghosh T, Raj GB, Dash KK (2022) A comprehensive review on nanotechnology based sensors for monitoring quality and shelf life of food products Measurement: Food 100049.

47. Rajput V, Minkina T, Sushkova S, Behal A, Maksimov A, et al. (2020) ZnO and CuO nanoparticles: a threat to soil organisms plants and human health Environmental Geochemistry and Health 42(1): 147-158.

48. Jafarzadeh S, Jafari SM (2021) Impact of metal nanoparticles on the mechanical barrier optical and thermal properties of biodegradable food packaging materials Critical reviews in food science and nutrition 61(16): 2640-2658.

49. Handy RD, Clark NJ, Boyle D, Vassallo J, Green C, et al. (2022) The bioaccumulation testing strategy for nanomaterials: correlations with particle properties and a meta-analysis of in vitro fish alternatives to in vivo fish tests Environmental Science: Nano 9(2): 684-701.

50. Farshad O, Heidari R, Zamiri MJ, Retana-Márquez S, Khalili M Ebrahimi M, et al. (2020) Spermatotoxic effects of single-walled and multi-walled carbon nanotubes on male mice Frontiers in veterinary science 7: 591558.

51. Huang X, Liu Y, Zou Y, Liang X, Peng Y, et al. (2019) Encapsulation of resveratrol in zein/pectin core-shell nanoparticles: Stability bioaccessibility and antioxidant capacity after simulated gastrointestinal digestion Food Hydrocolloids 93: 261-269.

52. Jia M, Zhang W, He T, Shu M, Deng J, et al. (2020) Evaluation of the genotoxic and oxidative damage potential of silver nanoparticles in human NCM460 and HCT116 cells International journal of molecular sciences 21(5): 1618.

53. Allan J, Belz S, Hoeveler A, Hugas M, Okuda H, et al. (2021) Regulatory landscape of nanotechnology and nanoplastics from a global perspective Regulatory Toxicology and Pharmacology 122: 104885.

54. Foulkes R, Man E, Thind J, Yeung S, Joy A, et al. (2020) The regulation of nanomaterials and nanomedicines for clinical application: Current and future perspectives Biomaterials science 8 materials science 8(17): 4653-4664.

Citation: Mohan Kumar, Madhuri Chaurasia and Sulekh Chandra*. Pioneering Nanotechnology in the Landscape of Food Science. Insi in Chem & Biochem. 2(5): 2023. ICBC. MS.ID.000550. DOI: 10.33552/ICBC.2023.02.000550.