materials proceedings

MDPI

Proceeding Paper

Applications of Nanomaterials in Food Industry: A Review †

Gamze Ozcakir

Chemical Engineering Department, Faculty of Engineering, Bilecik Seyh Edebali University, Bilecik, Turkey; gamze.ozcakir@bilecik.edu.tr

† Presented at the 4th International Online Conference on Nanomaterials, 5–19 May 2023; Available online: https://iocn2023.sciforum.net.

Abstract: The functionalization of nanostructured materials finds many applications in the food industry. Some of these areas are; nanosensors and new packaging materials. Nanosensors are used for detection of toxic and nonedible components in food. In food packaging, it can be possible to obtain antioxidant featured nanomaterials by using nanoparticles, nanofibers, nanocrystals, nanoemulsions. It is important to find suitable food nanomaterial for consumer and environment. So, the researchers also studied about harmfulness of food nanomaterials on human in case of a long time usage.

Keywords: nanosensors; food packaging materials; nanotoxicology

1. Introduction

Nanotechnology can be defined as designing, producing and applicating of the materials whose size are in the nanoscale range (1–100 nm) [1]. Nanomaterials can be sorted two groups with respect to their material and shape. Material group includes metallic, carbon, organic, boron nitride, mineral and silicon. While shape group involves quantum dot, nanowire, nanofiber, aerogel, nanorod, nanosheet and nanotube, etc. [2]. Nanomaterials have unique features such as high surface energy, adsorption capacity, and biological effectiveness. To degrade the size of material to the nanoscale improves some chemical and physical properties of the material such as diffusivity, strength, solubility. So, they have low density, high stability chemically, mechanically and kinetically. Because of these unique features of nanomaterials, nanotechnology can be applied several areas such as medicine, agriculture, environment and food [3]. Within the scope of medicine, it has been known that carbon quantum dots can be a promising candidate to drug delivery in the cancer treatment because of its some properties such as high biocompatibility, small size and low toxicity [4]. Besides that, Xie et al. (2022) showed that mesoporous silica aerogels can be effective as potential carrier in antibacterial agent delivery applications [5]. Another study showed that metal organic frameworks can be used in magnetic resonance imaging (MRI) and computed tomography (CT) for clinical diagnosis [6]. In agricultural basis, one of the studies is possessed by Tran et al. in 2023. The researchers observed that gold added ZIF-67 can be a solution to detect some harmful pesticides in raman spectroscopy rapidly and with high sensitivity [7]. Besides that, Siddiqui et al. (2022) produced a few layer MoS_2 nanosheet which can be a long-lasting soil moisture sensor [8]. There are also so many studies in literature which are about nanomaterial using in environmental issues. For example, it has been presented that graphene based nanomaterials can be effective on polycyclic aromatic hydrocarbons (PAHs) removal from wastewater by adsorption processes [9]. Zhang et al. (2022) possess an interesting review article about nanomaterials using in electromagnetic wave absorption. They revealed that MoS_2 nanosheets are among of them [10]. Alavi et al. (2020) used graphene nanoplatelets and ZnO nanoparticles to degrade used lubricating oil which composed of environmentally hard decomposable hydrocarbons via pyrolysis [11]. Saleem et al. (2022) showed in their paper that nanomaterial based

Citation: Ozcakir, G. Applications of Nanomaterials in Food Industry: A Review. *Mater. Proc.* **2023**, *5*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 5 May 2023

sensors can be effective on the detection of harmful gases like sulphur dioxide, hydrogen sulphide [12]. Yu et al. (2020) carried out a research about dye adsorption with hybrid nanomaterials based adsorbents. They observed that the adsorbent which composed of carbon nanofibrils and graphene nanoplates reached 1178.5 mg g^{-1} and 585.3 mg g^{-1} adsorption capacity for methylene blue and congo red dyes respectively [13]. Hu et al. (2021) used ZIF-67 type nanomaterial to produce glycerol carbonate by carbon dioxide-glycerol conversion [14]. Martinez et al. (2022) have research about catalytic biodiesel production by using magnetic nanonoparticles which are carrier for enzyme [15].

Interestingly, all foods which are plant of animal based include nanomaterials. For example DNA has 2.5 nm width. Besides that, milk has nano sized components like whey protein and lactose [16]. Nowadays, nanotechnology can be mainly used for packaging and nanosensing in food sector. Another important topic is nanotoxicology originates from nanomaterial using in food [17]. The aim of the study is to reveal novel studies about these topics in food industry.

2. Nanomaterials for Food Packaging

It is important to produce to packaging material which has resistance to steam and atmospheric gases. Besides that, mechanical and thermal stability are another desired properties for food packaging. Up to now, non-biodegradable petroleum based plastic packaging materials have been used in food industry. Nowadays, with respect to green approach, researchers have been studied in nanomaterials for food packaging [18]. In Figure 1, it was shown the most used nanomaterials in food packaging.

Figure 1. The most eminent nanomaterials for food packaging applications in literature.

2.1. Metallic Nanomaterials

Metal and metal oxide nanomaterials can be used in food packaging to enable antibacterial and antifungal properties of the packaging material. Ag, Cu metals and zinc, copper, iron and titanium oxides are mainly used nanoparticles for this purpose [19]. Ameen (2022) synthesized bi metallic (copper and silver) nanoparticles to maximum yield and reached inhibition of three human pathogens with this packaging material [20]. Lu et al. (2022) revealed that specifying the size of TiO_2 nanoparticles can be prevented its harmful damage on human cells. They proposed 110–300 nm scale as suitable range [21].

2.2. Carbon Nanomaterials

Carbon nanomaterials provide long shelf life to the food. And it has not any contamination effect on food. Carbon-based nanomaterials are synthesized through green routes mainly. They enable antibacterial protection to the food which is preserving. In food packaging, carbon dots, graphene, carbon nanotubes can be used [22]. Goh et al. (2016) synthesized polylactic acid-graphene food packaging material to enable mechanical stable, biodegradable, resistance against oxygen and steam. This material can increase shelf life of potato chips [23].

2.3. Organic Nanomaterials

Natural and edible biopolymers (starch, chitosan, gelatin, agar) are used to protect food. Chitosan is known as non-toxic and stable mechanically. However, it has low moisture resistance. So, researchers improved this property by reinforcing it with nanomaterials. They can be called as chitosan-based nanocomposite films [24,25].

2.4. Silicon Nanomaterials

It has been reported that silica aerogel incorporation to the food packaging polyvinyl alcohol film increased thermal stability and steam resistance for chocolate packaging [26]. However, it revealed that silica nanoparticles can be harmful on human cells [27].

3. Nanosensors

Nanosensors have been used for screening pathogens and chemicals in the food. Nanosensors are designed to detect environmental changes such as temperature, humidity, gas composition. Nanosensors are classified as chemical nanosensors and nano biosensors. There are several nanosensor based applications in food industry. Nanoelectromechanical systems (NEMS) can be applied to detect food pathogens. Electronic nose can be used for wine discrimination. Carbon nanotube based sensors are utilized to measure capsaicinoids in chilli peppers [28]. Contemporary researches about nanosensing in food industry were given in Table 1.

Table 1. Current nanosensing applications in literature for food applications.

Material	Application	Reference
molecularly imprinted silica layers appended to quantum dots (MIP-QDs)	fluorescence sensor to detect saxitoxin toxin in shellfish	Sun et al. (2018) [29]
Rhodamine B/UiO-66-N_3	H_2S detection via reaction-based ratiometric fluorescent nanosensor	Gao et al. (2021) [30]
SnO_2 Nanowires	gas sensor to distinguish methanol from ethanol in alcoholic beverages	Tonezzer et al. (2022) [31]
carboxylated multi-walled carbon nanotubes (c-MWCNT)-modified screen-printed electrode-based bionanosensor	detecting the time of ripening of tomato with respect to its malic acid concentration	Dalal et al. (2017) [32]
a glassy carbon electrode (GCE) modified with calixarene and gold nanoparticles	detecting two toxic food dyes (metanil yellow and fast green)	Shah (2020) [33]

4. Nanotoxicology

Nanotoxicology refers to as the generated problems in human health and environment which originate from nanomaterials. Several physochemical properties determine whether the nanomaterial will be toxic or not such as particle size, chemical composition, surface area, shape, crystallinity, structure, surface functional groups/charge, surface coating, and reactivity. These properties can be adjusted by synthesis methods [34]. As an alternative to toxic nanomaterials, researchers have studied on incorporating nanomaterials into biopolymers. Because, biopolymers are regarded as biodegradable, renewable, non-toxic, and environmentally safe materials. Proteins, polysaccharides, and lipids derived from plants or animals are in the biopolymers class. Besides that, biopolymers can be produced by using microorganisms like bacteria [35]. In the last year, Gautam et al. published a research about producing biopolymers from waste foods [36]. It was an interesting and green topic for food recycling. In Figure 2, it was presented waste food processing to produce biopolymers.

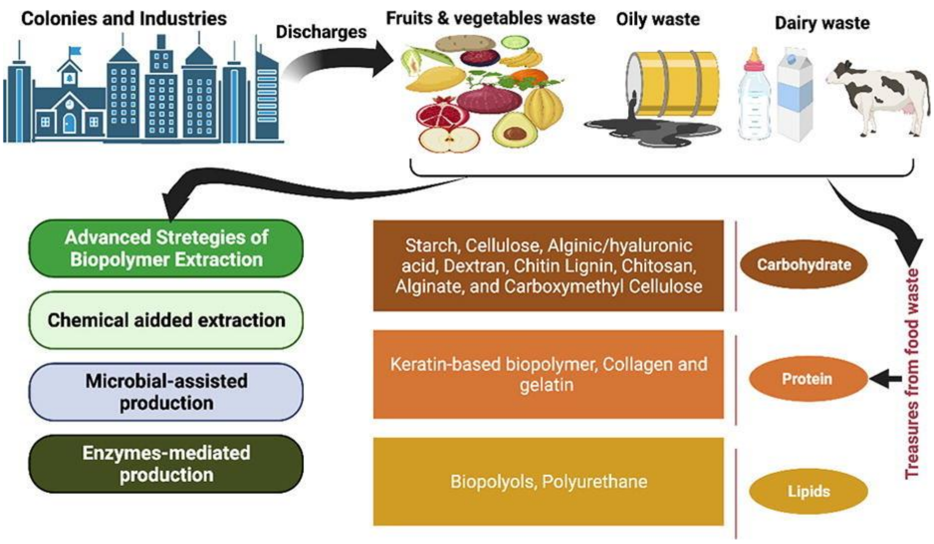

Figure 2. Biopolymer production route from food waste [36].

5. Conclusions

Materials which have nano-size possess several unique properties compared to the other materials such as stability under chemical and mechanical conditions, low density, high surface energy and adsorption energy. High surface energy of a nanomaterial originates from high surface area/volume of this matter. So, the nanomaterials can be used in so many areas like agriculture, medicine, food industries and environmental applications. In food industry, nanotechnology takes place in food packaging, biosensing and chemical sensing applications mainly. In food packaging, nanomaterials are important candidate because petroleum based plastics are used in this area mostly. Carbon materials come to the forefront in food packaging as an alternative material bacause they can be synthesized by applying green routes and they don't create any contamination with the food which is packaging. On the other hand, nanosensors are designed for detecting chemicals and toxic materials which can occur in the food. The materials like quantum dots, carbon nanotubes, gold nanoparticles can be used as nanosensor applications. However, it is important that selecting the true nanomaterial which has not any hazardous effect on environment and human health. So, nowadays nanotoxicology which caused by nanomaterial used in food area is an crucial issue.

References

1. Blecher, K.; Nasir, A.; Friedman, A. The growing role of nanotechnology in combating infectious disease. *Virulence* **2011**, *2*, 395–401.
2. Piperigkou, Z.; Karamanou, K.; Engin, A.B.; Gialeli, C.; Docea, A.O. Emerging aspects of nanotoxicology in health and disease: From agriculture and food sector to cancer therapeutics. *Food Chem. Toxicol.* **2016**, *91*, 42–57.
3. Chausali, N.; Saxena, J.; Prasad, R. Recent trends in nanotechnology applications of bio-based packaging. *J. Agric. Food Res.* **2022**, *7*, 100257.

4. Jana, P.; Dev, A. Carbon quantum dots: A promising nanocarrier for bioimaging and drug delivery in cancer. *Mater. Today Commun.* **2022**, *32*, 104068.
5. Xie, H.; He, Z.; Liu, Y.; Zhao, C.; Guo, B.; Zhu, C.; Xu, J. Efficient Antibacterial Agent Delivery by Mesoporous Silica Aerogel. *ACS Omega* **2022**, *7*, 7638–7647.
6. Wang, H.S. Metal–organic frameworks for biosensing and bioimaging applications. *Coord. Chem. Rev.* **2017**, *349*, 139–155.
7. Tran, H.N.; Nguyen, N.B.; Ly, N.H.; Joo, S.W.; Vasseghian, Y. Core-shell Au@ ZIF-67-based pollutant monitoring of thiram and carbendazim pesticides. *Environ. Pollut.* **2023**, *317*, 120775.
8. Siddiqui, M.S.; Mandal, A.; Kalita, H.; Aslam, M. Highly sensitive few-layer MoS2 nanosheets as a stable soil moisture and humidity sensor. *Sens. Actuators B Chem.* **2022**, *365*, 131930.
9. Queiroz, R.N.; Prediger, P.; Vieira, M.G.A. Adsorption of polycyclic aromatic hydrocarbons from wastewater using graphene-based nanomaterials synthesized by conventional chemistry and green synthesis: A critical review. *J. Hazard. Mater.* **2022**, *422*, 126904.
10. Zhang, S.; Cheng, B.; Gao, Z.; Lan, D.; Zhao, Z.; Wei, F.; Wu, G. Two-dimensional nanomaterials for high-efficiency electromagnetic wave absorption: An overview of recent advances and prospects. *J. Alloy. Compd.* **2022**, *893*, 162343.
11. Alavi, S.E.; Abdoli, M.A.; Khorasheh, F.; Nezhadbahadori, F.; Bayandori Moghaddam, A. Nanomaterial-assisted pyrolysis of used lubricating oil and fuel recovery. *Energy Sources Part A Recovery Util. Environ. Eff.* **2020**, 1–15.
12. Saleem, H.; Zaidi, S.J.; Ismail, A.F.; Goh, P.S. Advances of nanomaterials for air pollution remediation and their impacts on the environment. *Chemosphere* **2022**, *287*, 132083.
13. Yu, Z.; Hu, C.; Dichiara, A.B.; Jiang, W.; Gu, J. Cellulose nanofibril/carbon nanomaterial hybrid aerogels for adsorption removal of cationic and anionic organic dyes. *Nanomaterials* **2020**, *10*, 169.
14. Hu, C.; Yoshida, M.; Chen, H.C.; Tsunekawa, S.; Lin, Y.F.; Huang, J.H. Production of glycerol carbonate from carboxylation of glycerol with CO2 using ZIF-67 as a catalyst. *Chem. Eng. Sci.* **2021**, *235*, 116451.
15. Martínez, S.A.H.; Melchor-Martínez, E.M.; Hernández, J.A.R.; Parra-Saldívar, R.; Iqbal, H.M. Magnetic nanomaterials assisted nanobiocatalysis systems and their applications in biofuels production. *Fuel* **2022**, *312*, 122927.
16. Magnuson, B.A.; Jonaitis, T.S.; Card, J.W. A brief review of the occurrence, use, and safety of food-related nanomaterials. *J. Food Sci.* **2011**, *76*, R126–R133.
17. Shafiq, M.; Anjum, S.; Hano, C.; Anjum, I.; Abbasi, B.H. An overview of the applications of nanomaterials and nanodevices in the food industry. *Foods* **2020**, *9*, 148.
18. Huang, Y.; Mei, L.; Chen, X.; Wang, Q. Recent developments in food packaging based on nanomaterials. *Nanomaterials* **2018**, *8*, 830.
19. Kodithuwakku, P.; Jayasundara, D.; Munaweera, I.; Jayasinghe, R.; Thoradeniya, T.; Weerasekera, M.; Kottegoda, N. A review on recent developments in structural modification of TiO2 for food packaging applications. *Prog. Solid State Chem.* **2022**, 100369.
20. Ameen, F. Optimization of the synthesis of fungus-mediated bi-metallic Ag-Cu nanoparticles. *Appl. Sci.* **2022**, *12*, 1384.
21. Lu, N.; Chen, Z.; Song, J.; Weng, Y.; Yang, G.; Liu, Q.; Liu, Y. Size Effect of TiO2 Nanoparticles as Food Additive and Potential Toxicity. *Food Biophys.* **2022**, *17*, 75–83.
22. Raul, P.K.; Thakuria, A.; Das, B.; Devi, R.R.; Tiwari, G.; Yellappa, C.; Kamboj, D.V. Carbon nanostructures as antibacterials and active food-packaging materials: A review. *ACS Omega* **2022**, *7*, 11555–11559.
23. Goh, K.; Heising, J.K.; Yuan, Y.; Karahan, H.E.; Wei, L.; Zhai, S.; Chen, Y. Sandwich-architectured poly (lactic acid)–graphene composite food packaging films. *ACS Appl. Mater. Interfaces* **2016**, *8*, 9994–10004.
24. Kumar, S.; Mudai, A.; Roy, B.; Basumatary, I.B.; Mukherjee, A.; Dutta, J. Biodegradable hybrid nanocomposite of chitosan/gelatin and green synthesized zinc oxide nanoparticles for food packaging. *Foods* **2020**, *9*, 1143.
25. Petkoska, A.T.; Daniloski, D.; D'Cunha, N.M.; Naumovski, N.; Broach, A.T. Edible packaging: Sustainable solutions and novel trends in food packaging. *Food Res. Int.* **2021**, *140*, 109981.
26. Chen, C.; Ding, R.; Yang, S.; Wang, J.; Chen, W.; Zong, L.; Xie, J. Development of thermal insulation packaging film based on poly (vinyl alcohol) incorporated with silica aerogel for food packaging application. *Lwt* **2020**, *129*, 109568.
27. Guo, Z.; Martucci, N.J.; Liu, Y.; Yoo, E.; Tako, E.; Mahler, G.J. Silicon dioxide nanoparticle exposure affects small intestine function in an in vitro model. *Nanotoxicology* **2018**, *12*, 485–508.
28. Thiruvengadam, M.; Rajakumar, G.; Chung, I.M. Nanotechnology: Current uses and future applications in the food industry. *3 Biotech* **2018**, *8*, 1–13.
29. Sun, A.; Chai, J.; Xiao, T.; Shi, X.; Li, X.; Zhao, Q.; Chen, J. Development of a selective fluorescence nanosensor based on molecularly imprinted-quantum dot optosensing materials for saxitoxin detection in shellfish samples. *Sens. Actuators B Chem.* **2018**, *258*, 408–414.
30. Gao, X.; Sun, G.; Wang, X.; Lin, X.; Wang, S.; Liu, Y. RhB/UiO-66-N3 MOF-based ratiometric fluorescent detection and intracellular imaging of hydrogen sulfide. *Sens. Actuators B: Chem.* **2021**, *331*, 129448.
31. Tonezzer, M.; Bazzanella, N.; Gasperi, F.; Biasioli, F. Nanosensor Based on Thermal Gradient and Machine Learning for the Detection of Methanol Adulteration in Alcoholic Beverages and Methanol Poisoning. *Sensors* **2022**, *22*, 5554.
32. Dalal, A.; Rana, J.S.; Kumar, A. Ultrasensitive nanosensor for detection of malic acid in tomato as fruit ripening indicator. *Food Anal. Methods* **2017**, *10*, 3680–3686.
33. Shah, A. A novel electrochemical nanosensor for the simultaneous sensing of two toxic food dyes. *ACS Omega* **2020**, *5*, 6187–6193.

34. Leudjo Taka, A.; Tata, C.M.; Klink, M.J.; Mbianda, X.Y.; Mtunzi, F.M.; Naidoo, E.B. A review on conventional and advanced methods for nanotoxicology evaluation of engineered nanomaterials. *Molecules* **2021**, *26*, 6536.
35. Taherimehr, M.; YousefniaPasha, H.; Tabatabaeekoloor, R.; Pesaranhajiabbas, E. Trends and challenges of biopolymer-based nanocomposites in food packaging. *Compr. Rev. Food Sci. Food Saf.* **2021**, *20*, 5321–5344.
36. Gautam, K.; Vishvakarma, R.; Sharma, P.; Singh, A.; Gaur, V.K.; Varjani, S.; Srivastava, J.K. Production of biopolymers from food waste: Constrains and perspectives. *Bioresour. Technol.* **2022**, 127650.