Decontamination of Fresh-Cut Produce Using Photo-Active Carbon Nanoparticles: Current Status and Challenges

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Abstract

Fresh-cut fruits and vegetables (FCFV) consumption has increased significantly in recent years. The FCFV products are susceptible to microbiological contamination due to the cutting and grating processes. These processes will promote biological changes and consequently lose the quality. Several technologies are used to preserve the quality of fresh-cut produce, such as irradiation of ultraviolet light, edible coatings, heat treatment, and use of natural compounds, *etc.* In the present article, we propose the synthesis approach for photo-active carbon nanoparticles for their use in the decontamination of fresh-cut fruits and vegetables. The carbon nanoparticles are considered an emerging nanomaterial for biomedical applications because of near-infrared fluorescence carbon dots (NIR CDs) activity, low-toxicity, abundance, biocompatibility, and excellent photostability. The importance of carbon nanoparticles as a photo-active material and the current status of the research on photo-active carbon nanoparticles have been discussed.

Keywords: Photo-active materials; Carbon nanomaterials; Fresh-cut fruits; Microbiological contamination; Infrared fluorescence.

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1 Introduction

The trend to use fresh-cut fruits and vegetables in a regular diet is increasing not only in India but worldwide due to their ability to provide vitamins, dietary fiber, and minerals.^[1] When the fruits or vegetables are processed to change their physical appearance but keep them in fresh form, they are called fresh-cut produce.^[2] It comprises cut fruits, salad mixes, and many more forms.^[3] Their use in the diet helps in minimizing the probability of many health disorders.^[1] The presence of moisture, favorable pH conditions, and damaged surfaces during processing make the fresh-cut produce vulnerable to microbial attack. The microorganisms get favorable conditions for growth on fresh-cut produce as compared to intact produce.^[4] In this case, the chances of microbial contamination of fresh-cut produce increases. Many a time, fresh-cut produce comes from the fields irrigated with wastewater.^[5] There are numerous other sources with which the produce can come in contact with.^[6] Many recent incidences of disease spread happened because of the

consumption of contaminated fresh-cut produce.^[7] The most commonly linked pathogens to fresh produce include bacteria, parasites, and viruses,^[8] with *Escherichia coli* (*E. coli*) and *Salmonella* being the most abundantly found pathogens in outbreaks related to fresh-cut produce.^[9] Therefore, fresh-cut produce should be decontaminated to make it safe for consumption. However, they usually cannot be decontaminated by conventional heating treatments since it alters their properties. Some physical methods are employed for decontamination of fresh-cut produce, such as shear forces, ultrasound, high pressure, ionizing radiation, *etc.* (Fig. 1) But all these methods have their own limitations. Also, various chemical sanitizers are commonly used.^[10,11] However, these sanitizers' effect gets reduced due to the presence of many other materials and microorganisms on the surface of produce. The effective sanitizer concentration doesn't reach to microorganisms to inactivate them. The food industries use high concentration of sanitizers to overcome this constraint.^[11,12]

This generates toxic by-products.^[13] To overcome these limitations, there is a need to develop a new process to decontaminate the fresh-cut produce. The use of photo-active carbon nanoparticles will help to establish such an approach. These types of nanoparticles have small particle size, large and hydrophobic surface.^[14] They don't need surface modification.

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Fig. 1 Emerging and safe technology to preserve the quality of fresh-cut fruits and vegetables.

They can be synthesized easily on large scale using a variety of starting materials. They can be synthesized using solvents as well. The use of toxic components can be avoided.^[15,16]

Recently researchers used carbon nanoparticles to kill cancer cells via surface plasmon resonance (SPR) property^[17] (Neumann *et al.*, 2013). The carbon nanoparticles are suitable candidates for photothermal activity. They exhibit several properties (Fig. 2).

- 1) They shuttle electrons by suppressing the electron-hole recombination reaction.
- 2) They absorb light and act as sensitizers.
- 3) This generates a significant amount of heat.
- 4) It also induces phonon resonances.
- 5) They show excellent biocompatibility.^[18]

Considering all these facts, we are proposing the synthesis of photo-active carbon nanoparticles. The heat generated after exposure of nanoparticles to sunlight is sufficient to rupture bacterial cell membranes and kill them without damaging food materials.

Fig. 2 Properties of carbon nanoparticles.

2. Current status of research on the photo-active carbon nanoparticles

2.1 International status

Several research groups demonstrated the great potential of photothermal therapy (PTT) for the selective treatment of cancer cells^[19,20] bacteria,^[21,22] viruses,^[21,23] and DNA^[23] targeted with gold nanospheres, nanoshells, nanorods, and nanosphere clusters. This type of therapy is effective for selectively killing cancer cells and protecting healthy cells.^[19] A study reported selective photothermal lysis of pathogens. In this study, gold nanorods were synthesized. These researchers covalently attached primary antibodies to nanoparticles. These antibodies were specific for *Pseudomonas aeruginosa*.^[24] Addae *et al.*^[25] studied the inactivation of *B. anthracis* spores and cells using PTT activity of Au/CuS. They found that Au/CuS NPs were effective for inactivating *B. anthracis* cells, only and not the spores. A study reported the antibacterial activity of gold nanorods (Au-NRs) using PTT against oral microorganisms. They synthesized AuNRs by the seed and growth solution method. Their results suggest that Au-NRs could be used to control oral pathogens and biofilms.^[26] Santos *et al.*^[27] developed a rapid photothermal bacterial inactivation technique using irradiating near-infrared (NIR) light and nanoporous gold disks (NPGDs). In another study, Liu *et al.*^[28] developed a nanoplatform. This nanoplatform released PES upon exposure to NIR. The released PES inhibited HSP70 and thereby reducing bacterial tolerance to PTT. This resulted in enhanced pathogen destruction. The authors also suggested that it is possible to reuse PDA@Fe₃O₄ + PES. Similarly, few studies reported the photothermal effect of carbon nanoparticles against tumors and pathogens. Bao *et al.*^[29] developed sulfur and nitrogen codoped NIR carbon dots (CDs). These CDs showed high PTT efficiency in mouse models. They were able to visualize the effect using photoacoustic imaging.^[29] Tu *et al.*^[30] used activated carbon to synthesize carbon nanoparticles of less than 10 nm size. They showed that NIR irradiation of carbon nanoparticles effectively killed cancer cells. In a recent study, Wang *et al.*^[31] synthesized bismuth/cobalt nanoparticles (Bi@Co@CN) and coated them with multifunctional nitrogen-rich carbon. Their results showed that synthesized nanoparticles were reusable and biocompatible, generating ROS and photothermal conversion of materials. The combined effect killed *S. aureus*.

2.2 National status

We did not find any report regarding the use of either carbon or metal nanoparticles for PTT. However, few researchers used carbon nanoparticles for other applications. Mangrulkar *et al.*^[32] synthesized a composite of carbon nanoparticles and platinum nanoparticles (CNPs/Pt). The photocatalytic activity of CNPs/Pt was used for hydrogen generation. In another study, Roshni and Ottor^[33] used a thermal pyrolysis method for the synthesis of carbon nanoparticles from coconut milk. They used these nanoparticles for the detection of mercury.

3. Industry relevance of the use of photo-active carbon nanoparticles

Due to increasing awareness towards health, people are using

fresh-cut fruits and vegetables as diet supplements. Also, due to lack of time, people prefer to purchase packed cut fruits and vegetables. Therefore, the sales and intake of fresh-cut commodity have risen up in current years. India is the second-largest producer of vegetables and the fourth-largest producer of fruits in the world, which value Rs. 7000 crores.^[34] Considering these developments, India's food industries evolve with novel technologies and skillful promotion initiatives.^[1] Still, there is a need to adopt skillful processing techniques of fresh-cut produce to preserve and protect the product as they are extremely perishable.

The fresh-cut produce can get contaminated with microorganisms (some of them might be pathogenic) during production at the field, during handling and during processing at the food processing industries. Therefore, the food industries need to make sure that the product they produce should be microorganism free. For this, the industries have to apply decontamination processes. But they cannot use harsh processes since many of the food materials get destroyed during the process. The Physico-chemical methods used by the industries have their own limitations and sometimes revealed hazardous to human health. Therefore, there is an urgent need to find alternative treatment strategies to decontaminate the fresh-cut produce to increase shelf life and make it safe for human consumption. The photo-active carbon nanoparticles can be such an alternative to address this problem. The concept of photo-active carbon nanoparticles will explore the possibility of developing photo-active carbon nanoparticles, including packaging materials for several types of food materials. It will protect the environment by avoiding the use of harmful chemicals currently being used in the food packaging industry. Overall, this will reduce the processing cost of food industries and thereby final product cost. It will also reduce the spread of foodborne outbreaks and hence, reduce the economic burden of end-users.

4. Conclusion

A healthy diet and its benefits have increased the demand for fresh-cut fruits and vegetables (FCFV). The processing applied to fresh-cut produce may cause microbiological contaminations and result in short shelf life. An efficient, non-toxic mechanism is required to enable the fresh-cut fruit and vegetables to extend the shelf life and preserve the quality of the product. Due to their excellent properties, the photo-active carbon nanomaterials can be used in the food industry to minimize biological contaminations.

Supporting information

Not applicable

Conflicts of interest

All contributing authors declare no conflicts of interest.

References.

[1] O. Yousuf, S. Titikshya, A. Singh, *Int. J. Chem. Stud.* 2018,

6, 2229.

[2] O. Qadri, B. Yousuf, A. Srivastava, *LWT-Food Sci. Technol.*, 2018, **89**, 198-209. doi: 10.1016/j.lwt.2017.10.051.

[3] J. B. James, T. Ngarmsak, Processing of fresh-cut tropical fruits and vegetables: A technical guide, Rap publication (2010/16).

[4] A. Allende, L. Jaxsens, F. Devlieghere, J. Debevere, F. Artes, *J. Food Protect.*, 2002, **65**, 1573. doi: 10.4315/0362-028x-65.10.1565.

[5] Y. Pachepsky, R. Shelton, J. McLain, J. Patel, R. Mandrell, *Advan. in Agronomy*, 2011, **113**, 73.

[6] L. Calvin, *Int. Trade Food Saf.*, 2002, 828, 96.

[7] R. Callejón, M. Rodríguez-Naranjo, C. Ubeda, R. Hornedo-Ortega, M. Garcia-Parrilla, A. Troncoso, *Foodborne Pathog. Dis.*, 2015, **12**, 38.

[8] R. B. Tauxe, *Emerg. Infect. diseases*, 1997, **3**, 425.

[9] A. Mukherjee, D. Speh, E. Dyck, F. Diez-Gonzalez, *J. Food Protect.*, 2004, **67**, 900. doi: 10.4315/0362-028x-67.5.894.

[10] F. Artés, A. Allende, *Eur. J. Hortic. Sci.*, 2005, **70**, 245. doi: 10.1016/B978-012676757-5/50028-1.

[11] M. Fatica, *CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Resour.*, 2009, 4. doi: 10.1079/PAVSNNR20094052.

[12] K. Hassenberg, M. Geyer, M. Mauerer, U. Praeger, *LWT Food Sci. Technol.*, 2017, **79**, 354. doi: 10.1016/j.lwt.2017.01.030.

[13] M. Gil, M. Selma, F. López-Gálvez, A. Allende, *Int. J. Food Microbiol.*, 2009, **134**, 37-45. doi: 10.1016/j.ijfoodmicro.2009.05.021

[14] P. Maddigpu, B. Sawant, S. Wanjari, M. Goel, D. Vione, R. Dhodapkar, *J. Hazard. Mater.*, 2017, **343**, 165. doi: 10.1016/j.jhazmat.2016.09.075.

[15] S. Baker, G. Baker, *Angew. Chem., Int. Ed.*, 2010, **49**, 6726. doi: 10.1002/anie.200906623.

[16] A. Kokorina, E. Prikhozhenko, G. Sukhorukov, A. Sapelkin, I. Goryacheva, *Russ. Chem. Rev.*, 2017, **86**, 1171.

[17] O. Neumann, C. Feronti, A. Neumann, A. Dong, K. Schell, B. Lu, E. Kim, M. Quinn, S. Thompson, N. Grady, P. Nordlander, M. Oden, N. Halas, *Proc. Natl. Acad. Sci.*, 2013, **110**, 11681. doi: 10.1073/pnas.1310131110.

[18] E. Graham, C. Macneill, N. Levi-Polyachenko, *Nano Life*, 2013, **35**, 3523. doi: 10.1142/S1793984413300021.

[19] C. Pitsillides, E. Joe, X. Wei, R. Anderson, C. Lin, *Biophys. J.* 2003, **84**, 4032. doi: 10.1016/S0006-3495(03)75128-5.

[20] L. Hirsch, R. Stafford, J. Bankson, S. Serksen, B. Rivera, R. Price, J. Hazle, N. Halas, J. West, *Proc. Natl. Acad. Sci.*, 2003, **23**, 1354. doi: 10.1063/1.4967377.

[21] V. Zharov, J. Kim, D. Curiel, M. Everts, *Nanomedicine*, 2005, **1**, 345. doi:10.1016/j.nano.2005.10.006.

[22] V. Zharov, K. Mercer, E. Galitovskaya, M. Smeltzery, *Biophys. J.*, 2006, **90**, 627. doi: 10.1529/biophysj.105.061895

[23] M. Everts, V. Saini, J. Leddon, R. Kok, M. Stoff-Khalili, M. Preuss, C. Leigh Millican, Guy Perkins, Joshua M. Brown, Hitesh Bagaria, David E. Nikles, Duane T. Johnson, Vladimir

P. Zharov, and David T. Curielet, *Nano Lett.*, 2006, **6**, 587-591. **Author information**

doi: 10.1021/nl0500555.

[24] R. Norman., J. Stone, A. Gole, C. Murphy, T. Sabo-Attwood, *Nano Lett.*, 2008, **8**, 306. doi: 10.1021/nl0727056.

[25] E. Addae, X. Dong, E. McCoy, C. Yang, W. Chen, L. Yang, *J. Biol. Eng.*, 2014, **8**, 11. doi: 10.1186/1754-1611-8-11

[26] J. Castillo-Martínez, G. Martínez-Castañón, F. Martínez-Gutiérrez, N. Zavala-Alonso, N. Patiño-Marín, N. Niño-Martínez, V. Zaragoza-Magaña, C. Cabral-Romero, *J. Nanomater.*, **5**, 2015. doi: 10.1155/2015/783671.

[27] Gregg M. Santos, Felipe Ibanez de Santi Ferrara, Fusheng Zhao, Debora F. Rodrigues, and Wei-Chuan Shih, *Opt. Mater. Express*, 2016, **6**, 1217. doi: 10.1364/OME.6.001217.

[28] D. Liu, L. Ma, L. Liu, L. Wang, Y. Liu, Q. Jia, Q. Guo, G. Zhang, J. Zhou, *ACS Appl. Mater. Interfaces*, 2016, **8**, 24462. doi: 10.1021/acsami.6b08119.

[29] X. Bao, Y. Yuan, J. Chen, B. Zhang, D. Li, D. Zhou, P. Jing, G. Xu, Y. Wang, K. Holá, D. Shen, C. Wu, L. Song, C. Liu, R. Zbořil, S. Qu, *Light: Sci. Appl.*, 2018, **7**, 91. doi: 10.1038/s41377-018-0090-1. eCollection 2018.

[30] X. Tu, Y. Ma, Y. Cao, J. Huang, M. Zhang, Z. Zhang, *J. Mater. Chem. B*, 2014, **2**, 2192. doi: 10.1039/C3TB21750G.

[31] Wang L., Shen B, Pan D., *Nano Res.* **6** (2013) 325. doi: 10.1007/s12274-013-0308-8

[32] Priti A. Mangrulkar, Abhay V. Kotkondawar, Sumanta Mukherjee, Meenal V. Joshi, Nitin Labhsetwar, D. D. Sarma and Sadhana S. Rayalu, *Energy Environ. Sci.*, 2014, **7**, 4087-4094. doi: 10.1039/C4EE02444C.

[33] V. Roshni, Divya Ottoor *J. Luminescence*, 2015, **161**, 117-122. doi: 10.1016/j.jlumin.2014.12.048.

[34] S. Rawat, *Asian J. Plant Sci. Res.*, 2015, **5**, 56.

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