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Review

Influence of nanoparticles on food: An analytical assessment

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ABSTRACT

Nanotechnology is a novel frontier transforming traditional food sector into an emergent, dynamic and innovative food industry. The swift advancement of nanotechnology has been expediting the alterations of conventional food principally the creation of elegant and vibrant packaging and for betterment of quality of food and its safety, various new nanomaterials have been created. Advances in nano-packaging, nano-biosensors, and nanofood are the foremost recent progressions of nanoscience. Technology based on nanoscience has a vital impact on the quality, safety, and packing of food materials. Nanotechnology application enables preservation of food, increases shelf life, and facilitates nutrition enrichment. In spite of the enormous benefits of nanotechnology, there are vital concerns regarding its usage; since the accumulation of nanoparticles (NPs) in human beings and environment can result in various safety and health hazards.

In the present article, current trends in nanotechnology are examined, and the utmost difficult tasks and favorable prospects in the food sectors are focused. The toxicological basics and risk evaluation of nanomaterials in these novel foods are also reviewed. For balanced and sustainable advancement, the possible use of bio-inspired and biosynthesized nanomaterials is emphasized. Though, vital queries regarding higher performing, lesser noxious nanomaterials should be focused to enable dynamic progress and use of nanotechnology. In order to manage the usage, production, handling, treatment, and discarding of nanomaterials; legislation and regulation are of great importance. To reinforce awareness among public and acknowledgement of the new nano-enabled foods, hard work needs to be done. In conclusion, nanotechnology proposes an overabundance of prospects, by delivering a new and workable substitute in the food industry.

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1. Introduction

Nanotechnology is altering our whole social order and it is extensively used in our daily life. Novel methodologies of nanotechnology in food industry, the utmost current progresses made in the domain of nanostructured constituents that have substantial influence on the food sector. Since, the present food segment demands modernization, nanotechnology combined with novel interdisciplinary methods and processing procedures has empowered significant developments capable of transforming the food industry. Nanotechnology can help to determine tasks confronted by the food and bioprocessing companies for progressing and executing systems that can yield quantitative and qualitative foods that are viable, harmless, and biodegradable. After the Department of Agriculture of United States printed the first ever roadmap in September 9, 2003 nanotechnology has started stepping in food industry (US DOA, 2003). During the last decade, research work on this subject has risen steeply. It nearly covered every single aspect in the food industry including packing and processing of food. (Christopher et al., 2021; Silvana et al., 2020; Xiaojia et al., 2019; Dasgupta and Ranjan, 2018).

The beverage and food segment are a worldwide multi trillion-dollar business (Xiaojia et al., 2019; Cushen et al., 2012). By the year 2020, a current evaluation of the universal economic effect of nanotechnology is anticipated to be at least \$3 trillion. Globally, this may operate 6 million labors in the expanding nanotechnology

trade (Roco et al., 2011). It has motivated several food companies occupied in the progress and promotion of innovative nanomaterial centered foods and shooting up manufacturing competence, safety, taste, and various features of food. Incredibly, there are hundreds of products that have already been marketed and used in the food business. During the last decade, there are more than hundreds of foods that have been promoted and consumed in the food industry. With an exception to iron oxide and titanium dioxide which have been used as colorant and food pigment respectively, neither a single nanomaterial comprising products have been put into the food used by humans. The essential cause is that legislation and regulation is restricted concerning nano food, particularly because of the intricacy of nanomaterials and legislating processes (Kumar et al., 2020; Daniela et al., 2019).

2. Nanomaterial synthesis

Nanomaterials having one dimension varying from 1 to 100 nm are covered in Nanotechnology. Various techniques are accessible for synthesizing several kinds of nanomaterials in form of colloids, particles, powders, tubes, clusters, rods, wires, and thin films. The synthesis techniques are categorized in three prime techniques (physical, chemical, and biological) for synthesis of nanomaterials as depicted in the self-explanatory (Fig. 1). The technique created

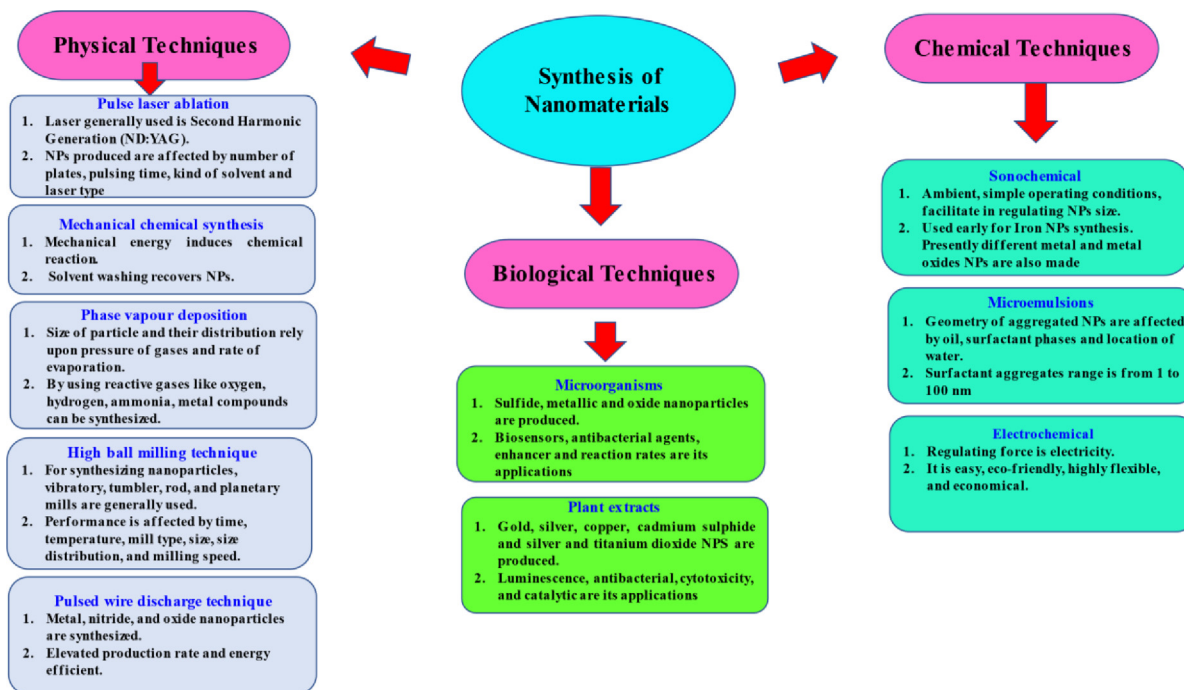


Fig. 1. Synthesis of Nanomaterials.

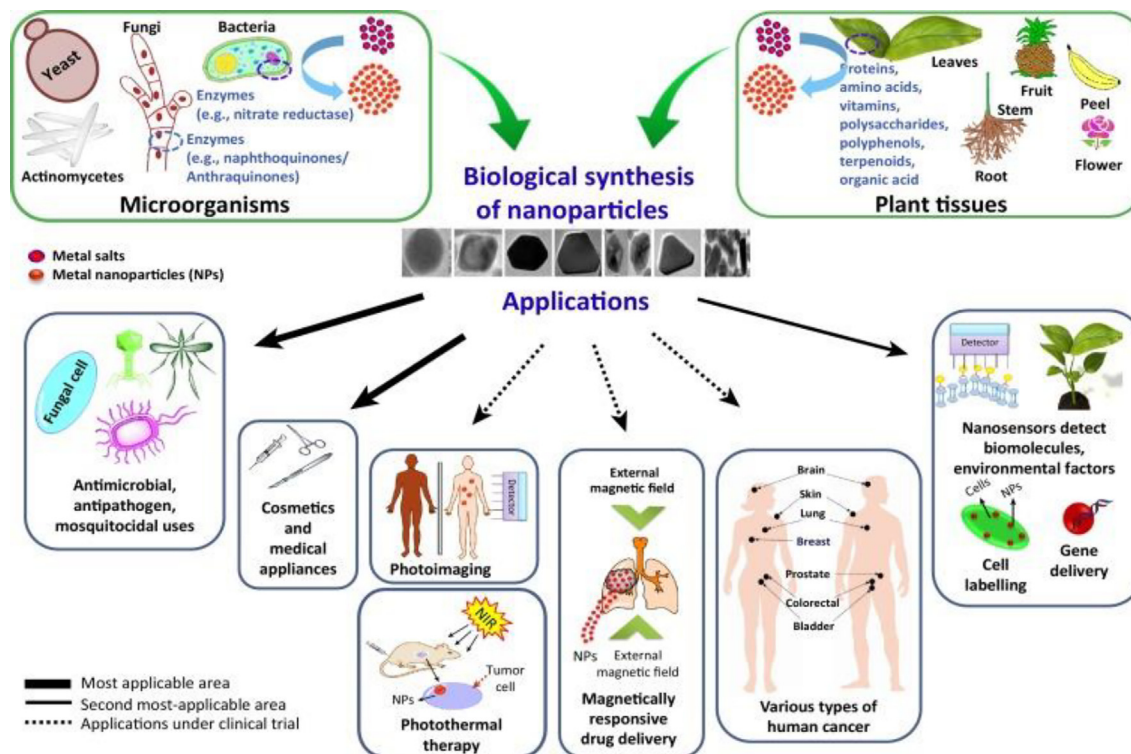


Fig. 2. Biotic synthesis and NPs application. Reproduced with permission from Singh et al. (2016a).

is upon the basis of the kind of nanostructures like nanowires, nanoplates, quantum dots, and nanorods.

1. Physical techniques: Evaporation and mechanical forces are normally used in synthesizing nanomaterials. Some physical techniques used for synthesizing nanomaterials are mechanical chemical synthesis, pulse laser ablation, physical vapor deposition through consolidation, high ball milling, and pulsed wire discharge method (Ubaidullah et al., 2020a; Ameta et al., 2020).
2. Chemical techniques: Chemical techniques have few benefits over physical like synthesis at a low temperature of less than 350 °C, potential of making different shapes and sizes of nanoparticles, simple transition of end products in liquid form to thin films or dry powder, and possibility of assimilation of iron atoms while synthesis (Mateja et al., 2021; Al-Enizi et al., 2020a; 2020b; Ubaidullah et al., 2020b). The chemical techniques are sonochemical, microemulsion, and electrochemical (Monalisa et al., 2021).
3. Biological techniques: The benefits of synthesizing nanomaterials by using biological techniques are simple scaling-up, non-toxicity, ecofriendly, reproducibility in making, and distinct morphology. The biological techniques involve the synthesis of nanoparticles by microorganisms like yeasts, bacteria, fungi and by plant extracts. (Yogita et al., 2021; Shivraj et al., 2020; Singh, 2016).

3. Biosynthesized nanoparticles

For viable and green environment friendly chemistry process, biosynthesis has become a recent trend for the advancement and design of various NPs (Fig. 2). Several parts of plants for example fruits, roots, leaves, and their extracts and various biological organisms including fungi, yeast, enzymes, bacteria, and actinomycetes have exhibited assuring appropriateness for the biosynthesis of NPs as listed (Table 1).

Most of the researchers have stated three important benefits:

- 1) in order that a lesser number of hazardous substances will be utilized through the engineering procedures, biological system as producing host can act as reducing, capping and stabilizing agent.
- 2) the usage of unsafe chemicals and resources for energy gets alleviated by biosynthesis which often takes place in neutral pH and ambient pressure and temperature.
- 3) because of the surface functionalization throughout the biosynthesis procedure, majority of the biosynthesized nanoparticles are less toxic and biocompatible.

As a replacement for applying chemical capping, reducing, and stabilizing agents, biological systems can perform as operative elements. Previous researches have shown that macrobiomolecules for example lipids and proteins having operative carboxyl and amide groups could be adsorbed on the surface of NPs, that means it might be participating in the stabilization of Au NPs (Christopher et al., 2021; Silvana et al., 2020). Moreover, the function of biomolecules in nanomaterial synthesis as capping agent is reported in many studies (Table 1). Furthermore, for biological systems; neutral pH, ambient pressure, and temperature are the normal requisites. Chemical synthesis of nanomaterials is frequently done and is often carried out at extreme pH and high pressure, temperature (Mateja et al., 2021; Monalisa et al., 2021).

4. Recent status on food nanotechnology

In food industry, tested nanomaterials comprise of organic (natural product nanoparticles), inorganic (metal and metal oxide nanoparticles) and both organic and inorganic for example clay. Amongst all metal nanoparticles, gold nanoparticle is generally considered as a detector/sensor whereas silver nanoparticle because of its antimicrobial action is used mostly for commercial

Table 1
Certain illustrations of biosynthesized nanoparticles.

Biological model	Biogenic nanoparticles	Classification	Characteristics	Note	References
Aquatic algae					
Brown alga <i>Cystoseira trinoids</i>	CuO nanoparticles	XRD, TEM (7-10 nm), Raman, FE-SEM (6-7, 8 nm), EDX, AFM	Antioxidant, antibacterial and catalytic in nature	Stabilizing and reducing	(Gu et al., 2018)
Macroalga <i>Sargassum muticum</i>	ZnO nanoparticles	FESEM, FTIR, XRD, 30- 57 nm, UV- vis	Not applicable		(Azizi et al., 2014)
Plant extracts					
Root of red ginseng	Silver and gold nanoparticles	EDX, UV-vis, TEM (10-30 nm)	Antimicrobial action	Stabilizing and reducing	(Singh et al., 2016b)
Seeds of Coffee Arabica	Silver nanoparticles	FTIR, DLS (20-30 nm), UV-vis, TEM, XRD, SEM-EDXA	Mic \leq 0.2675 mg/L on <i>S. aureus</i> and <i>E. coli</i>		(Dhand et al., 2016)
Leaf of <i>Cassia tora</i>	Silver nanoparticles	SEM, FTIR, EDAX and XRD	Antibacterial and antioxidant actives	Plant extract is used as a reducing agent	(Adio et al., 2017)
<i>Aloe vera</i>	Nanoscale zero-valent iron	EDS, FTIR, TGA, FESEM and XRD	Elimination of arsenic and selenium from water	Plant extracts is used as a reducing agent	(Saravanakumar et al., 2015)
Leaf of <i>Atrocarpus altilis</i>	Silver nanoparticles	FTIR, XRD, EDX, SEM (34 nm), TEM (38 nm) and DLS (162.3 nm)	Antioxidant and antimicrobial	Phyto ingredients as capping agent	(Ravichandran et al., 2016)
Leaf of <i>Nigella sativa</i>	Silver nanoparticles	SEM 15, nm, UV-vis, FTIR	Lesser cytotoxicity and phytotoxicity than wet –chemistry synthesis ones (30 nm)	Extract of plant is used as capping and reducing agent	(Amooghaie et al., 2015)
Oranges and Pineapples	Silver nanoparticles	SEM (10-300 nm), UV-vis	Not applicable	Reducing agent	(Hyllested et al., 2015)
Leaf of <i>Butea monosperma</i>	Silver and gold nanoparticles	XRD, TEM, XPS, FTIR, DLS, UV-vis	Inhibition of cancer cell creation	Extract of plant is used as reducing, stabilizing /capping agent	(Patra et al., 2015)
Bark of <i>Butea monosperma</i>	Silver nanoparticles	TEM, FTIR, XRD, EDX and DLS (98.28 nm)	Antibacterial action and cytotoxic impact on human myeloid leukemia cell line.	Capping and reducing agent	(Pattanayak et al., 2017)
Fruit of Longan	Silver nanoparticles	TEM (4-10 nm), XRD, EDX, FTIR, UV-vis	Enzymatic browning reduction on white cabbage. MIC .31.25 μ g/ml against <i>Staphylococcus aureus</i> and <i>Bacillus subtilis</i> , 62.5 μ g/ml against <i>E.coli</i>	Reducing, stabilizing /capping agent	(Khan et al., 2016)
Bacteria					
<i>Serratia sp.</i> BHU-S4	Silver nanoparticles	XRD, EDXA, FTIR and TEM (10-20 nm)	Used as fungicide against phytopathogen <i>biplaris sorokiniana</i> instigating spot blotch disease in wheat plants	Stabilization and reduction	(Mishra et al., 2014)
<i>Pichia fermentans</i> JA2	Zinc oxide and silver nanoparticles	XRD, UV-vis, and FE-SEM-EDX analysis	Silver NPs contained majority of the G ⁻ clinical pathogens; ZnO nanoparticles contained only <i>Pseudomonas aeruginosa</i>	Synergistic effect exhibited with antibiotics	(Chauhan et al., 2015)
<i>Bacillus cereus</i> srtain HMH1	Magnetic iron oxide nanoparticles	FT-IR, 29.3 nm .FE-SEM, DLS,, EDS UV-vis, and VSM	Lesser cytotoxicity: IC ₅₀ MCF7->5 mg/ml and IC ₅₀ , 3T3> 7.5mg/ml	Stabilizing and capping agent	(Fatemi et al., 2018)
Fungi					
<i>Aspergillus flavus</i> TFR 7	TiO ₂ nanoparticles	EDX, DLS, TEM (12-15 nm)	Stimulate plant G root length (%49.6+) shoot length (%17+) root area (%43+) and root nodules (%67.5+) Encourage rhizosphere microbes	From rhizosphere soil, fungi is isolated	(Raliya et al., 2015)
<i>Saccharomyces cerevisiae</i>	Silver nanoparticles	FTIR, UV-vis, XRD, TEM	Photocatalytic degeneration of methylene blue	Biomolecules act as capping and reducing agent	(Roy et al., 2015)
<i>Aspergillus flavus</i> and <i>Emericella nidulans</i>	Silver nanoparticles	FTIR, EDX, Hexagonal-and triangular-shaped DLS (36-531 nm, 37-340 nm), XRD TEM (30-150 nm, 10-450 nm)	Antibiofilm and synergistic antibacterial action	Capping and reducing agent	(Barapatre et al., 2016)
Yeast					
<i>Candida lusitaniae</i>	Silver chloride / silver nanoparticles	SEM-EDS, FIB/SEM, UV-vis, XRD, TEM	Antimicrobial action	From gut of termite, yeast is isolated	(Eugenio et al., 2016)
<i>Magnusiomyces ingens</i> LH-F1	Gold nanoparticles	FTIR, SEM, UV-vis, SDS-PAGE, DLS, TEM	Catalytic reducing of nitrophenols	Reducing, stabilizing /capping agent	(Zhang et al., 2016)
<i>Rhodotorula glutinis</i> and <i>Cryptococcus laurentii</i>	Silver nanoparticles	FTIR, UV-vis, TEM (15-220 nm), XRD	Antifungal action against <i>Phytopathogenic fungi (Aspergillus niger, Penicillium expansum, Botrytis cinerea, Rhizopus</i> and <i>Alternaria species)</i>	From apple peel yeast is isolated	(Fernández et al., 2016)

Table 1 (continued)

Biological model	Biogenic nanoparticles	Classification	Characteristics	Note	References
Actinomyces Strain NH21 of Streptomyces Isolated VITBN4	Gold and silver nanoparticles CuO nanoparticles	UV-vis, FTIR, AFM, TEM XRD (61.7 nm), TEM (61.7 nm) DLS (198 nm), FTIR, EDX, SEM, UV-vis	Antibacterial action Antibacterial action against fish and human bacterial pathogens	Capping agent, isolated from acidic soil Stabilization, reduction and capping agent, isolated from soil sample	(Skadanowski et al., 2017) (Nabila and Kamabiran, 2018)
Enzymes Alpha amylase	TO ₂ nanoparticles	FTIR, XRD, TEM	MIC of 62.5 µg/ml <i>Escherichia Coli</i> and <i>Staphylococcus aureus</i>	Enzyme is used as capping and reducing agent	(Ahmad et al., 2015)

XRD = X-Ray Diffraction; TEM = Transmission electron microscopy; EDX = Energy Dispersive X-Ray Analysis; SEM = Scanning electron microscope; AFM = Atomic force microscope; UV-Vis = Ultraviolet-visible spectroscopy; FTIR = Fourier-transform infrared spectroscopy; FESEM = Field Emission Scanning Electron Microscope; AFM = Atomic force microscope; EDS or EDAX = Energy Dispersive X-Ray Analysis.

purpose. For flavor enhancing, disinfecting and food additives, titanium dioxide nanoparticles are widely applied. Natural product nanoparticles are used as constituents or enhancements in food industry (Yogita et al., 2021; Monalisa et al., 2021)

Various NPs have revealed great possibility and capability in every single phase of food industry and agriculture. Within several facets of consumer goods, food nanotechnology has penetrated for example food conservation, packing and supplements or additives. In safeguarding of food safety, nanotechnology has progressed the food treatment and storing processes (Monalisa et al., 2021). On nanometer scale, various chemicals supplemented as food additives or packing ingredients have been found partly existing. For example, in the nanometer range, food-grade TiO₂ NPs have been found up to roughly 40% (Dudefoi et al., 2017). Although TiO₂ NPs are usually acknowledged as lesser toxic at ambient conditions, long-term contact to such NPs may cause unfavorable effects (Mateja et al., 2021; Dorier et al., 2017). Certain NPs applied in food products are listed (Table 2). The major bases for regulation and legislation are United States Food and Drug Administration (U.S. FDA) and European Commission (EC) on food nanotechnology. On the basis of risk evaluation of the particle size of a substance, some authorizations are made by EC and U.S. FDA. Under research and development (R&D), a few applications are also comprised to designate possible future applications (Table 2).

5. Usage of nanoparticles in processing of food

Nanomaterials are widely used as carriers for food enhancement for example nanoemulsion and nanoencapsulation, preservatives, feeding foods used for animals, flavors or color additives (Vivek et al., 2018). The exclusive features and properties of nanomaterials which are engineerable may pose excessive benefits for processing of food as constituents or additives. Inorganic oxide chemicals allowed by the U.S. FDA are MgO (E530), TiO₂ (E171) and SiO₂ (E551) as food flavor carrier, food color additives and anti-caking agent (Table 2). In cake icing, puddings, candy, gum and white sauces TiO₂ is extensively used as a food additive (Kumar et al., 2020). Apart from titanium nitride and carbon black, present permissions on the chemicals enumerated in (Table 2) for processing of food are on the basis of conventional particle size. Besides foods being directly supplied to human beings, animal feeds also constitute a substantial part in the worldwide food business, ensuring safe and cheap manufacturing of products used for animals all over the world. U.S. FDA has considered zinc oxide, copper oxide and iron oxide as “generally recognized as safe” (GRAS) nutritive dietary enhancement in animal feeds (Table 2 A).

6. Application of nanoparticles in food packaging

In food industry, nanotechnology has been broadly studied, established and industrialized for food packing as an innovative solution (Emamhadi et al., 2020; Daniela et al., 2019). During production, carriage and storing, food contact ingredients are meant to openly contact food produces. Nanomaterials intended for food packing enjoy various benefits as related to traditional packing material. Because of their thermal, mechanical and barrier properties and lower cost, nano clay is generally used for food packing.

Based on the physiochemical properties of the nanomaterials, nanoclays are classified into various subclasses like bentonite, montmorillonite, halloysite, kaolinite and hectorite. Bentonite and Montmorillonite are now enumerated as GRAS and in Effective Food Contact Substance (FCS) regulations by the U.S. FDA (Table 2 B). FCS operates as the U.S. FDA in effect premarket guidelines for food contact materials that have been established to be safe and sound for their proposed usage. Nevertheless, recent study design-

Table 2
Recent status of nanotechnology-based food produces.

Nanoparticles used in processing of foods - A Usage	Nanoparticles	Producer	Recent status	Comment	Reference
Color flavorings	Synthetic iron oxide TiO ₂		Relieved from permit Relieved from permit	> 1% by food weight >0.25 (for cats and dogs) and 0.1 (human) % by complete food weight	(CFR, 2018) (https://www.ecfr.gov/cgi-bin/text) (U.S. FDA, 2015) (CFR, 2011) (https://www.ecfr.gov/cgi-bin/text) (EU 2011) (U.S. FDA 2018) https://www.accessdata.fda.gov
Additive Preservers Flavor carries Fruit and vegetables promotion Anticaking substances Nutritive dietetic enhancement	Carbon black Titanium nitride Iron oxide Aluminum oxide Silicon dioxide Cobalt oxide MnO (E530) ZnO Silver -silica Silica dioxide (E551) Silica dioxide (E551) Silica dioxide (E551) Copper oxide Iron oxide Zno	Nanox intelligent particles	Approved by EC 10/2011: not sanctioned by the U.S. FDA as additive Approved by EC 10/2011 FCS ^a inventory Approved by EC 10/2008 Relieved from permit REG ^b Generally recognized as safe	No passage stated, to be used in PET Bottles only upto 20 mg/kg. > 2.5% w/w in the polymer Approval established on conservative dimensions of particles FCN NO. 1235 4 > ppm by silver weight blended into polymers as an antimicrobial agent >10,000 mg/kg, not including infant foods and foods for young children >2% of the solid ink >2% by food weight Approved for use as animal fodder	(U.S. FDA 2018) https://www.accessdata.fda.gov Euroapen Commision. Regulation (EC, 2008) https://eur-lex . (CFR, 2017) (https:// www.ecfr.gov/cgi-bin/text-) (CFR, 2018) (https://www.ecfr.gov/cgi-bin/text) (U.S. FDA 2018) https://www.fda.)
Nanoparticles food contact packing- B Usage	Nanoparticles	Producer	Recent status	Comment	Reference
Pesticides identification Pathogens identification	Zinc Oxide QDs Fluorescent nanosensor Plasmonic nanosensors Magnetic nanosensors		Generally recognized as safe Research and development		(Sahoo et al. 2018) (Kearns et al. 2017)) (Banerjee et al. 2016)
Toxins identification	Phosphorescent QDs Plasmonic nanosensors		Research and development		(Sun et al. 2018) (Zhang et al. 2016)
Edible film/covering	Chitosan/Nano-Silica Covering Nanoemulsion/ Quinoa Protein/ Chitosan Poly-ε-caprolactone Nanoemulsion with lemongrass essential oil Bio-nano-hybrid pectins and LDH salicylate Bentonite (Al ₂ O ₃ 4SiO ₂ nH ₂ O)		Research and development (Generally recognized as safe)	Test done on Longan fruit Test done on fresh strawberries Test made on fresh cut red delicious apples Test done on fresh –cut - Fuji apples Test made on fresh apricots Test done on fresh –cut - Fuji apples U.S. FDSA 21 CFR 184.1155	(Shi et al. 2013) (Robledo et al. 2018) (Zambrano-Zaragoza et al. 2014) (Salvia-Trujillo et al. 2015) (Gorrasi and Bugatti, 2016) (CFR 2018) https:// www.ecfr.gov/cgi-
Flame Retardation additive, gas barrier, etc. Prevent abrasive wear	Montmorillonite Montmorillonite chromium (iii) oxide Nanoemulsion with lemongrass essential oil	Poly One corporation Nanocor [®] inc. Toyo Seiken Kaisha Limited and Nanocor Incorporated. Oerlikon Balzers covering AG, Oerlikon surface solutions AG.	FCS ^a inventory	FCN NO. 1163 FCN NO. 932. FCN NO. 1839. For usage at a thickness not exceeding 200 nm, not used in contact with human milk and infant formula.	(U.S. FDA 2018) https://www.accessdata.fda.gov (Gorrasi and Bugatti, 2016) (Salvia-Trujillo et al., 2015)

Table 2. (continued)

Usage	Nanoparticles	Producer	Recent status	Comment	Reference
Deter abrasive wear heat enhancer in Polyethylene terephthalate (PET) polymers	Titanium aluminum nitrite Tin antimony oxide	Balzars Aktengesellschaft Nyacol Nano Technologies, Inc	(Generally recognized as safe) FCS ^a Inventory	FCN NO. 302. The utmost thickness of the coating of surface must not exceed 5 µm. FCN NO. 1437. less than 0.05 by polymer weight	(CFR 2018) https://www.ecfr.gov/cgi-bin/https://www.fda.gov/cfsdata/fda.gov/ (U.S. FDA 2018)

^a FCS: Effective food contact substance (FCS) notification.

^b REC: Food additives for which a petition has been filed and a regulation issued.

nates probable migration risks related with nano clay packing (Muthu et al., 2018; Störmer et al., 2017). For food storage and preservation, edible covering with nanomaterials encoded has also demonstrated wonderful potential. Coated fresh foods for example fruits and vegetables remains fresh throughout storage and transportation processes.

Other usages in food contact packing comprise of toxins detection (Daniela et al., 2019; Sun et al., 2018), pesticides detection (Monalisa et al., 2021; Sahoo et al., 2018) and pathogens detection (Kearns et al., 2017). These are under active research and advancement because of the ultra-sensitive tendencies of nanomaterials. A current report from Sahoo et al. (2018) discovered that ZnO quantum dots (QD) could be applied to distinguish several pesticides comprising glyphosate, atrazine, aldrin and tetradifon because of the fact that the pesticide comprising of strong leaving groups (e.g., -Cl) act together with QD rapidly with huge binding affinity at 10⁷ M⁻¹. Additionally, ZnO QD could also photocatalyze pesticides during interaction. In order to utilize sensors based on nanomaterials for examining the quality of food, “smart packaging” has become immensely popular.

7. Application of nanotechnology in food safety

Safety of food is an emerging concern for public health. The important aspect regarding food safety is that it does not pose any risk or harm to the user while consuming (Pal, 2017). Recent advances in nanotechnology have transformed the food manufacturing, by its several usages in food safety, processing, and security and also increasing nutraceutical worth and shelf-life and slashing packing waste (Wesley et al., 2014). Pathogens, contaminants, and toxins are a major risk for the health of human beings. Progresses in nanotechnology have enhanced the shelf-life, detection of toxins, and microbial contamination (Inbaraj and Chen, 2016). Moreover, nanomaterials as well as quantum dots, nanotubes made of carbon and nanoparticles containing metals could be utilized to make biosensors for the detection of food pathogens (Wesley et al., 2014)

Nanoparticle application for the ascertainment of food pathogens and toxins was stated (Burris et al., 2012). By using several nanostructured materials (NSMs) and organic receptors in a unified system, nano-biosensors are created as bioanalytical tools (Chandra et al., 2011). To ascertain the pathogens, present in food and substances that spoil the food, several kinds of biosensors have been created (Li et al., 2014). In food samples, biosensors based on fluorescent dye and magnetic NPs have been created for finding *Campylobacter* (Stutzenberger et al., 2007), *E. coli* (Cheng et al., 2009), and *Salmonella* (Fu et al., 2008). Food pathogens like *E. coli*, *Salmonella* sp., *Listeria monocytogenes* and mycotoxins present in food can be easily detected by applying specially designed biosensors (Durán and Marcato, 2013). In order to swiftly and precisely identify the microbes, surface enhanced Raman scattering (SERS) is used as nano-biosensing device. To find bacteria silver nano colloids are generally applied in SERS (Baranwal et al., 2016), since silver nano colloids increase Raman signs. In addition to silver nano colloids, silver NPs (Abbaspour et al., 2015), graphene oxide (Zuo et al., 2013), plasmonic gold (Fang et al., 2017), carbon nanotubes (Yang et al., 2013), and magnetic beads (Holzinger et al., 2014) are generally applied to find pathogens present in food. Ascertainment of *E. coli* present in food is possible now by the detection of scattering of light by cells. This sensor works by binding to an identified protein and represented as bacteria on a chip made of silicon having a tendency to bind further with other *E. coli* existent on the food (Bhattacharya et al., 2007). Synthesized DNA molecular beacons are utilized as nano-barcode to detect pathogens present in food (Li et al., 2004).

Chen and Durst (2006) created an immunosorbent assay based on array to find *Listeria monocytogenes*, *E. coli* O157:H7, and *Salmonella* sp., by applying G-liposomal nano-vesicles protein. DeCory et al. (2005) created a beadimmunoliposome assay to swiftly ascertain *E. coli* O157:H7 present in aqueous samples. Moreover, several investigators have used liposome-based techniques to detect pathogens (Shukla et al., 2016). Nano sensors like nano cantilevers use materials based on silicon to distinguish proteins and identify pathogens which vibrate at various frequencies subject to biomass (Jain, 2003). Thakur et al. (2018) found single bacterial cell of *E. coli* by applying a nanoparticle based diminished graphene field-influence transistor instrument. Moreover, by using magnet based nanoglodimmuno sensor, aflatoxins formed by *A. parasiticus*, and *Aspergillus flavus* that soil food could be identified (Tang et al., 2009).

8. Toxicologic fundamentals and risk evaluation

8.1. Exposure paths and their relations

The growing usage of nanomaterials in the food sector has fascinated public attentions over the past few years. Either the nanomaterials are purposefully put in as additives in food or involuntarily introduced through migration (Hannon et al., 2016) in numerous foodstuffs. Due to the exclusive physiochemical properties of nanomaterials, their applications and usage increases, subsequently raising apprehensions about the human health and ecology (He et al., 2018).

In ecology and environs, the performance and outcome of nanomaterials is mainly dependent on the physiochemical properties of the nanomaterials. Moreover, the intricacy of the conditions prevalent in the environment confines the probability of the performance and outcome of nanomaterials. Due to the intricate nano-bio-eco relations, it is hard to track and examine the allocation of nanomaterials (He et al., 2018). Though a universal methodology has been suggested for interpretation of the nano-bio-eco relations amongst the abiotic and biotic environments and nanomaterials in a linked ecosystem (He et al., 2014a), case-by-case investigations are required for a decisive evaluation of nanotoxicity in the environment.

8.2. Safety issues

In spite of the enormous advantages of NPs in food sector, there is immense concern related to their toxicity and noxious effect on environment. The prime aspects related to the behavior, fate, biological accessibility, disposal, and harmfulness of NPs to environment was described by Klaine et al. (2008). NPs are purposefully supplemented as food additives or coincidentally introduced through migration (Hannon et al., 2016) in various food products. Upfront exposure of buyers to NPs used in food sector jeopardizes the health of humans. Exposure is limited till the NPs remain in food packing. But there are high risks associated with the passage of NPs to humans by ingestion of food. Impact of NPs on health of humans and safety related to the usage of NPs was stated by Teow et al. (2011). They described the entries of NPs, their distribution and absorption in human bodies, emphasizing the cytotoxicity and genotoxicity. To have an understanding of the mode of action, behavior, and functioning of NPs in living systems, in order to develop safe nanotechnology, was described by Stark (2011). Various previous researches have disclosed the toxic effect of NPs used in food and packaging. The toxic effect of NPs on human organs relies on their physiochemical features like biological distribution and availability, concentration in food product and quantity of food ingested (Wani and Kothari, 2018). NPs like asbestos (Hett, 2004),

could activate immune response or settle down in brain (Scrinis, 2008).

Toxic assessment of Metal NPs was studied by Schrand et al. (2010), They stated that as NP size reduces, its toxic level enhances. Small NPs having high reactivity and capability to traverse membranes and capillaries could pile up in CNS (Central Nervous System) (Borm and Kreyling, 2004). Interaction of NPs with enzymes and proteins could trigger oxidative stress and production of ROS (Reactive oxygen species) inducing damage to mitochondria and cell, leading to cell death (He et al., 2014b). Overgeneration of ROS could damage neurons (Long et al., 2007), acute DNA damage (He et al., 2014b), autophagy (Khan et al., 2012) carcinogenesis, mutagenesis, and age-related illnesses in human beings. TiO₂ NPs could trigger tumorlike alterations in cells of human beings (Botelho et al., 2014) and anti-caking silica NPs could be cytotoxic in lung cells (Athinarayanan et al., 2014). Silver NPs affect fibroblast in human lungs by enhancing ROS, reducing ATP level, inducing chromosomal anomalies, and damaging mitochondria and DNA. (Kim et al., 2007). Carbon Nanotubes, generally used in food packing has toxic effects on human lungs and skin (Mills and Hazafy, 2009). Jovanović (2015) stated the accumulation of TiO₂ NPs in human bodies by eating chewing gums having TiO₂ NPs. Similarly, Athinarayanan et al. (2014) reported the accumulation of SiO₂ NPs in gut epithelia after eating food having E551. Various Metal NPs like CuO (Karlsson et al., 2013), Ag (McShan et al., 2014), and ZnO (Fukui et al., 2012) could have harmful effects in food stimulants by increasing intracellular ROS triggering peroxidation in lipids and damage to DNA (Fukui et al., 2012). Furthermore, there are less toxicological researches on NPs used in edible coatings and food packing. There are limited documented studies on prospective toxicity of NPs on human beings. Hence, risk assessment researches to identify the harmful and noxious effects of NPs on the health of human beings must be crucially investigated and *in silico*, *in vitro*, and *in vivo* analysis are required to standardize protocols for regulating safety issues and risk assessment related to the usage of NPs in food sector.

8.3. Data creating and its analysis

In food industry, systematic and precise evaluation of nanotoxicology is fundamental to safe use, sensible engineering, management and usage of nanomaterials. Additionally, recent procedures characteristically applied for toxicology deliver slight information that is beneficial for chemists to develop their sustainable blueprint for large scale application (Maertens and Plugge, 2018). On the basis of many research studies on cell damage both *in vivo* and *in vitro*, the toxicological figures are yet mostly restricted to extend any decisive statement regarding the regular pattern of exposure to nanomaterials and their noxious effect on the health of human beings. By means of model organisms and cell lines for example *Escherichia coli* (Gou et al., 2010) and cell lines of human A549 lung adenocarcinoma (Li et al., 2016), respectively, for producing omics figures is possibly the upcoming mechanism for the analysis of nanotoxicity. At the same time, machine learning methodology must be modified to study the increasing data.

9. Frontline issues

Even though various studies exhibited less noxious impact of nanomaterials in food produces (Xiaoja et al., 2019; Dufefoi et al., 2017), the noxiousness may get changed due to long-term exposure. Little is known about the biodistribution and bioavailability of nanomaterials therein and the severe and lasting toxicity upon coming in contact with them. Currently, France has decided to re-evaluate the safety of TiO₂ (E171) as additives in food at

the legislature level. French Agricultural Research Institute led research group in 2017, stated the pretumorous, non-malicious harms in the rat colons who were fed with TiO₂ NPs for >100 days (Bettini et al., 2017). Afterwards, agency for French Food safety assessed the French Agricultural Research Institute research and made suggestions on the carcinogenic capability of TiO₂ to European Chemicals Agency. In 2018, one of the amendments in French Farm and Food bill gets cleared in the National Assembly, is aimed to ban the promotion and trading in of TiO₂ food additives in food industry by 2020, though it is not yet finalized (France USDA, 2018). A U.S. based company; Dunkin Donuts has also said that they will stop the usage of TiO₂ NPs in their donuts. French confectionary subsidiary of Mars Inc., and Mars Chocolate, France, have by now declared to ban TiO₂. Advancement made on prohibiting the application of E171 is an illustration of how law and regulations would influence the usage and promotion of nano-food. Although nanotechnology has huge benefits, the prospect of nanotechnology in food manufacturing is still undefined because of their toxicity, laws and regulations and awareness and its acceptance in public.

There is an ongoing debate on the possible hazards of conventional nanomaterials. Additional information on risk evaluation is certainly essential. Furthermore, various strategies have been applied to decrease the noxiousness of engineered nanomaterials and in the meantime, enhance the choice and preference of target and performance consistency. In order to create engineered nanomaterials less toxic and more viable, precise tailoring on doping, morphological restrain and surface function has been established as real deals.

10. Public awareness and approval

Due to their antimicrobial properties, silver nanoparticles were added into various food and milk packings. Without having any information about the adding up of these nanoparticles, common public used these products. It leads to both legislative and ethical problems. Now a days, appropriate labeling becomes obligatory so that public is conscious of what they eat. It is producer's accountability to keep this data clear and accessible to the general public. Approval and awareness amongst public are a significant issue but it is frequently overlooked by a food producer as they tend to keep their expertise secret.

11. Assessment of nanotechnology

In each and every part of food manufacturing, nanotechnology shows favorable possibilities to be used extensively. It is based on restricted information attained primarily from laboratories. Taking into account, the uncertain ecological effect and the meager ability to regulate properties and material interaction at nanoscale level, the applied usage of nanotechnology and promoting nanomaterial centered produce remains undefined. In turn, it correspondingly confines the advancement of the legislator and regulatory bodies, additionally becoming a hindrance for publicizing of innovative goods. There is low level of awareness among public regarding food nanotechnology. Public needs to be notified regarding the status of food nanotechnology whereas food producers choose the contrary because their expertise is secret. For achievement in present biotechnology industry, applying ecologically responsive practices has become most crucial. Since, food manufacturing is a trillion-dollar business, numerous goods related to nanotechnology have been promoted globally for example packing materials. It will remain a challenge for the producer because of monitoring of safety codes by government legislatives.

12. Conclusion

Innovative researches and their consequent viable applications are emerging and amplifying their extent from one domain to another. There is enormous potential in nanotechnology for improving and evolving food industry across a broad spectrum covering numerous domains of specialties as well as embodying various facets of food management. In food industry and technology, nanotechnology has a bright role in enhancing shelf life, storage, safety, security, superior quality, high nutrition value, therapeutic and fortified food free from pathogens packed in an elegant and dynamic manner. Nanotechnology enables a drastic improvement in properties of food packing material but more studies and advancement are required to figure out the potential benefits and detriments. It enhances the functionality of food packing materials by improving the food properties like tasty, nutritious, and healthy food, when packed. It is generally acknowledged that nanofoods would be widely available to consumers globally in upcoming years.

The foremost concern for researchers and monitoring bodies are benefits to end users and food safety. Therefore, it is vital to invest monetary resources, innovative researches, and ample time to attain the commercialization of nanofoods. Various legislative agencies like FDA emphasize upon nanoparticle features for example size of particles, their hazardous properties, and correlation with their absorption in human intestines. The food companies must precisely pursue the guidelines issued by legislative bodies for example WHO and FDA to assess the safety, security, packing, storage, and usage of supplements in food. Limited documented work is available regarding safety of humans after oral consumption of nanoparticles and their distribution, absorption, and metabolism. It is essential to innovate novel tests for examining the noxious effects of NPs on the health of human beings and also exposure risks. Moreover, it is essential to formulate stringent monitoring guidelines regarding the safe usage of nanomaterials in food stuffs at world level. The application of computational and instrumentation science could enable scientists to have exceptional knowledge regarding toxicologic and hazardous impact of NPs on cell lines and tissues in human beings. Therefore social, scientific, and technical considerations are essential to augment the nanotechnology applications in various domains. Furthermore, it is also essential to engineer NPs with latest techniques to make them highly safe and effective in food sector.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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