NANOTECHNOLOGY: AN EMERGING TECHNOLOGY IN FOOD SECTOR

Abstract

Nanotechnology has emerged as a promising technological paradigm with the potential to revolutionize various industries, including the food sector. The application of nanotechnology in the food industry, exploring its impact on food production, processing, safety, and nutrition. The food industry faces numerous challenges, such as ensuring food security, extending shelf life, enhancing nutritional value, and reducing environmental impacts. In the domain of food production, nanotechnology facilitates the development of novel nanomaterials, such as nanoparticles and nanoemulsions, which possess unique functional properties. These nanomaterials can be incorporated into food packaging to create intelligent, active, and antimicrobial coatings that safeguard against spoilage and contamination, thereby prolonging the shelf life of perishable products. Nanotechnology also plays a crucial role in enhancing food safety. Advanced nanosensors can rapidly detect and identify contaminants, pathogens, and allergens in food products, enabling timely intervention and preventing widespread outbreaks. This chapter summarizes the possibilities for using nanoparticles in the food business to give customers food that is safe and free of contamination and to ensure that the food has enhanced functional features that will be accepted by consumers and there has also been a brief discussion of aspects of the application of nanotechnology in connection to improving food nutrition and organoleptic qualities of foods.

Keywords: Applications, Nanotechnology, Food, Nanoparticles, Nanomaterials.

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I. INTRODUCTION

Nanotechnology is a field of science and technology which deals with manipulating matter at the nanoscale level, which is the scale of individual atoms and molecules. However, it involves the understanding, control as well as utilization of materials and structures with dimensions typically ranging from 1 to 100 nm (1 nm is one billionth of a meter). Nanoscience and Nanotechnology are two new frontiers of this century. The technology allows scientists including engineers to design and creates materials, devices, and systems with unique properties and functionalities that differ significantly from those found in macro scale [1]. Adequate nutrition and well clean atmosphere promotes good human health [2]. In a scientific way, nanoscience defined as the study of phenomena as well as manipulation of materials at the atomic, molecular together with macro-molecular scales, where the properties are different from those at a larger scale moreover, have unique new functional applications [3].

Indeed, its applications to the agri-food sector are somewhat recent as compared with their usage in drug delivery and pharmaceuticals knowingly. Furthermore, sharp delivery of nutrients, biological separation of proteins, rapid sampling of biological & chemical contaminants in addition with nanoencapsulation of nutraceuticals are some of imminent topics of nanotechnology in food and agriculture sector respectively [1]. Many of the nanoparticles were traditionally used to the group of colloids (micelles, emulsions, mono and bi layers); these can attract towards each other by Vander Waals forces that provides colloidal stability. Nanotechnology is used to a limited extent; in spite of it has potential to revolutionize agriculture as well food sectors by their revolutionary scientific innovations [2]. In future, food technology is an area where it will play predominant role [4]. For food applications, two forms ofnanofoods namely food additives in which nanoparticles introduced inside and food packaging, nanoparticles introduced outside. However, main aim to nanoscale in food additives, to increase shelf life, nutritional composition, flavor enhancement and texture also, though it works as food quality indicators because detect food pathogens quickly. Nanotechnology mainly considered increasing shelf life of products, indicating spoilage ultimately increase overall quality of food products by preventing flow of gas across packaging [5]. Furthermore, two approaches applied in nanotechnology for food applications such as- "top down" and "bottom up" [6]. The top down approach is achieved by virtue of, physical processing of food materials like grinding and milling. Indeed, dry milling technology is used to procure wheat flour of very fine particles that has high water binding capacity [7]. In certain foods, naturally occurring bioactive compounds possess physiological benefits and help to reduce the risks certain lifestyle disorders, including cancer. The ω-3 and ω-6 fatty acids, including pre and probiotics, micronutrients have their advantages in food nanotechnology as bioactive compounds[8]. By minimizing the size of particles, nanotechnology bestow with to improve the properties of bioactive components, like solubility, prolonged residence time in the GI (Gastrointestinal Tract) tract, delivery properties in addition with effective absorption through cells [9].

Currently, nanoparticles are utilized by food industries, to obtain safe as well as nutritious food products free from microbial contamination, spoilage, bioavailability of nutrients, organoleptic features, influence consumer demands, enhance functional properties, increases market demand and acceptance [10]. Some examples of nanotechnology based food products are cooking oils which have neutraceutical within nanocapsules, nanocapsulated

flavor enhancers along with nanoparticles which have ability to free food from chemicals [11]. In food based industries, numerous innovative applications of nanotechnology are involved, including use of some nanoparticles in foods named as cubosomes, micelles, bipolymeric, and liposomes in addition with evolution of nanosensors which aims to ensure food safety [12, 13]. The nanomaterials used may enhance the qualitative as well as quantitative manufacturing of safe, healthy, wholesome including quality of foods which spoil very easily (perishable) in day-to-day life [10]. Some nanoparticles like gold, titanium dioxide, zinc oxide, silver including carbon are put together in ten folds comparable to others by means of their antimicrobial property [14]. However, nanoparticles have their size varies between 1 and 100 nm though manufactured by using several methods, also applied in numerous fields named as pharmaceuticals, electronics, engineering including food and agriculture respectively [15]. Nevertheless, increased attempts in marketing sector, research in nanotechnology of food as well as related products are only just genesis to develop [16].

II. APPLICATIONS OF NANOTECHNOLOGY

1. **Flavor Control:** Flavor is the most important element in food sector; indeed it attracts consumers towards products to buy. However, flavor plays crucial role in sensory attributes though influences consumption of particular food. Moreover, it is very complicated to control or stabilize flavors, especially during storage as well as manufacturing operations [17]. However, to slow the deterioration of flavor or losses during processing and storage, it is better to encapsulate the flavor prior to use in food in addition with enhancing chemical stability as well as providing controlled release. Some approved carriers are- gums (gum arabic, alginates including carrageenan), chitosan, biopolymers like carbohydrates (starch, dextrose, maltodextrins) and proteins (whey as well as gelatin) [18]. Thereafter, substances are packed into nanocarriers by nanoencapsulation which provides finished product functionality that involves liberation of core materials [19]. Flavors are encapsulated by safety carrier guard against interactions; moreover reactions are induced by light as well as oxidation. While designing an encapsulation system, some factors should be kept in mind are physico-chemical properties of flavor (solubility) alongwith carrier (viscosity). Therefore, carriers can't react with flavors [20].

2. **Enhancing the Bioavailability of Bioactive Compounds:** The bioavailability elucidate as, when bioactive compounds enters into the blood stream. Furthermore, it is most important consideration while producing functional foods. There is mandatory to increase the stability of bioactive compounds though their absorption is enhanced by epithelium cells, so that bioavailability can be increased. Various target delivery systems are using nanocarriers, for improving bioavailability of different bioactive components. Furthermore, can be categorized into two according to their solubility in water i.e. hydrophilic as well as lipophilic. Some examples of highly lipophilic molecules are- PUFA (polyunsaturated fatty acids), phytosterols, flavonoids, oil soluble vitamins in addition with curcuminoids. Nonetheless, lipophilic compounds have lower bioavailability with human gastrointestinal tract because of poor absorption in the GI fluids [21]. When compare to micro size carriers, nanocarriers anticipate an increased surface area additionally, strengthen the solubility including bioavailability of encapsulated bioactive compounds. Therefore, reduction of particle size enhances the

efficiency of delivery, solubility, in addition with biological activity of the compounds because of per unit greater surface area [22].

3. **Detection of Deleterious Substances in Food Products:** Nanotechnology is an ultra-modern technology, possessing key role in various fields. Even so, nanosensors are the devices which have capacity to detect as well as quantify the lower concentrations of many pathogens, organic compounds and further chemicals. Besides, these appliances have the potential to manifest high sensitivity, rapid response in addition with recovery and integrate addressable arrays on a wide reaching [23]. Nanosensorshave been applied for detection of mycotoxin and pathogen in foods. Normal control on these microorganisms is very tough, though during processing and storage operation with the help of nanosensorspromptly identifies toxins and pathogens present in foods. Additionally, used in smart packaging system, while contacting with several food pathogens sensor fluoresces in various colors [24]. Some examples of nanosensors introduction in foods are- organo phosphate used for diagnosis of pesticide present in fruit and water, semiconductors used for detection of pesticide 2,4-dichlorophenoxyacetic acid.

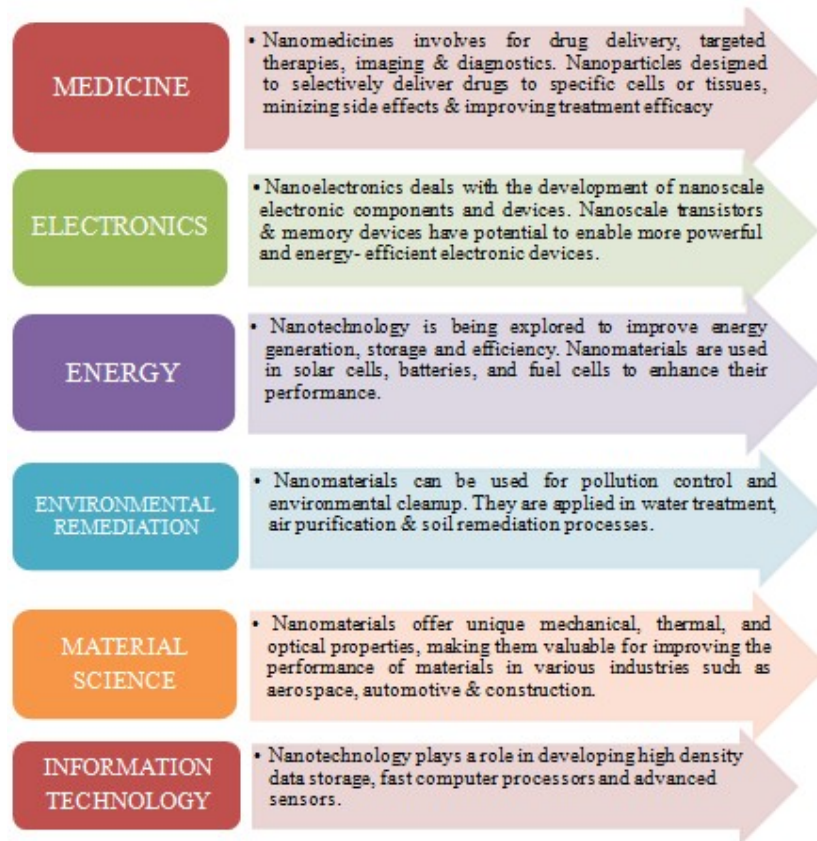## III. OTHER APPLICATIONS OF NANOTECHNOLOGY

MEDICINE - Nanomedicines involves for drug delivery, targeted therapies, imaging & diagnostics. Nanoparticles designed to selectively deliver drugs to specific cells or tissues, minizing side effects & improving treatment efficacy

ELECTRONICS - Nanoelectronics deals with the development of nanoscale electronic components and devices. Nanoscale transistors & memory devices have potential to enable more powerful and energy- efficient electronic devices.

ENERGY - Nanotechnology is being explored to improve energy generation, storage and efficiency. Nanomaterials are used in solar cells, batteries, and fuel cells to enhance their performance.

ENVIRONMENTAL REMEDIATION - Nanomaterials can be used for pollution control and environmental cleanup. They are applied in water treatment, air purification & soil remediation processes.

MATERIAL SCIENCE - Nanomaterials offer unique mechanical, thermal, and optical properties, making them valuable for improving the performance of materials in various industries such as aerospace, automotive & construction.

INFORMATION TECHNOLOGY - Nanotechnology plays a role in developing high density data storage, fast computer processors and advanced sensors.

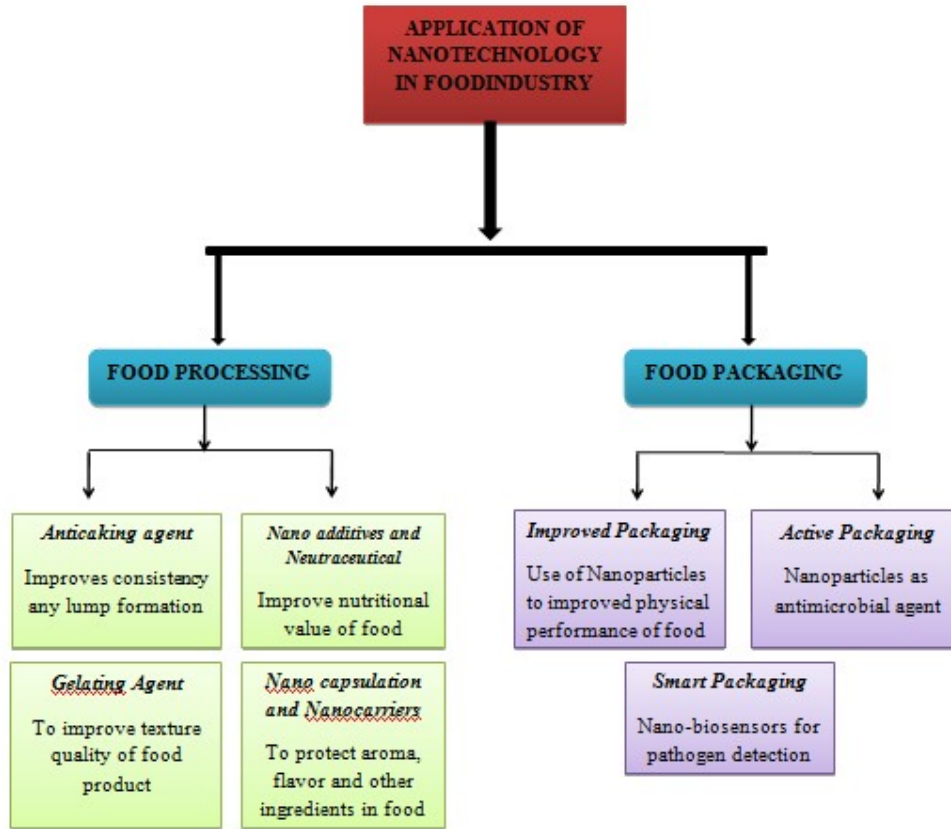**Figure 1**

IV. NANOTECHNOLOGY IN FOOD INDUSTRY

Figure 2

V. NANOTECHNOLOGY IN FOOD PROCESSING

The role of emerging nanotechnology in food processing industries, increases shelf-life of various kinds of food products in addition to let down the extent of wastage due to microbial infestations.However, nanopolymers are taking steps to displace ancient food packaging. In present scenario, nanocarriers are employs as delivery systems to carry food additives in different food materials with the absence of distributing their basis morphology. Size of particles could directly affect the conveyance of any bioactive components to numerous sites inside the body [25]. Furthermore, nanotechnology has been applicable in the genesis of emulsions, simple solutions, encapsulation, and biopolymer matrices in addition with association colloids which recommend coherent delivery systems with all qualities mentioned above. At the moment, nanosensors are used to confirm the existence of contaminants, mycotoxins, and various microorganisms present in food materials ultimately lead to spoilage [26]. The nanoparticles possess superior properties for encapsulation, though releases efficiency compared to conventional encapsulation system. Likewise, nanoencapsulations mask odor as well as tastes; additionally control dealing of active ingredients present inside the food matrix, control the liberation of active principle, make sure obtainability at a target time as well as specific rate also safeguard against moisture, heat, chemical, biological deterioration at the time of processing, storage, utilization, along

with reveals closeness with other compounds in the system [27]. Therefore, significance of nanotechnology in food processing system can be estimated by considering its important role in the augmentation of food products with regards to food:

Indeed, it is realistic fact that remarkably nanotechnology besides touching all above mentioned aspects also brought about notably modifications in different food products which anticipated innovative qualities respectively.

1. **Texture, Taste and Appearance of Food:** The nanotechnology technique imparts a range of alternatives to enhance quality of foods, also improves food taste. While, nanoencapsulation have been used predominantly to enhance release of flavor as well as retention [28]. However, rutin which is an ordinary dietary flavonoid possessing eminent pharmacological activities but because of its poor solubility, demand in food industry is definite. Moreover, ferritin nanocages is a encapsulation which increases its solubility, thermal including ultraviolet radiation stability of ferritin was trapped rutin when compares with free rutin[29]. Numerous metallic oxides like titanium dioxide in addition with silicon dioxide, traditionally have been used as a coloring or flowing agents in different food materials. Likewise, silicon dioxide nanomaterials also most commonly used as carriers of fragrance and flavors producing agent if food products [30]. Utilization of nanoemulsions to convey lipid-soluble bioactive compounds most popularized, afterward it can be produced by utilizing natural food materials, simple production methods also designed to strengthen water dispersion plus bioavailability [31].

2. **Nutritional Value:** In general, bioactive substances like carbohydrates, proteins, lipids, and vitamins are very vulnerable to an acidic environment as well as the enzymatic activity of the stomach and duodenum. Additionally, because these chemicals are less soluble in water while in non-capsulated form, encapsulation not only makes it possible for them to resist such harsh conditions but also makes it possible for them to be included into food products. To provide considerable health benefits, nanoparticles-based minute consumable capsules that aim to improve delivery of medications, vitamins, and delicate micronutrients in common foods are being developed. [32]. Further, the nanostructuration, nanoemulsification, nanocomposite are some techniques have been employed to encapsulate the substances in tiny forms to deliver nutrients such as antioxidant or protein more effectively for absolutely beneficial for nutritional as well as health.

3. **Shelf-Life:** The consumable coatings (nano) on different food materials, produce barrier against moisture as well as gas exchange, also provide antioxidants, colors, enzymes, flavors in along with anti-browning agents respectively; enhance the preservation quality of prepared food products, even though after opening of packed food. Chemical deterioration processes are delaying by encapsulation of functional elements with the droplets, by engineering the properties of layer (interfacial) surrounding them. Example: Curcumin (bioactive compound found in turmeric) possessing chief active and minimum stable properties, also exhibit less antioxidant activity while it is stable during pasteurization process or at various ionic strength upon encapsulation [33].

VI. NANOTECHNOLOGY IN FOOD PACKAGING

Food packaging is the most attractive element in food industry because it enhances appealing quality of specified products. Nanotechnology has shown great promise in various fields, including food packaging. It has the potential to enhance food safety, extend shelf life, and improve overall food quality. Somewhat, beneficial materials used in packaging should have restricted or no moisture moreover, gas permeability in amalgamation with biodegradability. Nowadays, nano base food packaging like "smart" and "active" packaging are most popular because it gives numerous advantages over traditional packaging methods also, deliver best packaging materials with highly raised mechanical strength including barrier properties, antimicrobial films to nanosensing for early diagnosis of pathogens and notifying consuming for safety purposes [34]. Intelligent packaging systems with embedded nanosensors can respond to external stimuli, such as temperature or gas composition changes. These smart packaging solutions can help ensure food safety and quality by indicating if the food has been exposed to unfavorable conditions during storage or transportation. On the other hand, incorporation of inert nanoparticles like silica, silicate along with clay nanoplatelets, chitosan and chitin into polymeric matrix, makes it resistance to fire, strengthen, lighter and also greater thermal properties.

Additionally, application of nanoparticles towards antimicrobial food packaging, two of them i.e. nano-composite and nano-laminates are vigorously applied for packaging, which confer barriers against thermal as well as thermal though prolong shelf-life of food products. Utilization of nanoparticles in polymeric compounds, assures the development of more withstand and cheaper packaging materials [35]. However, utilizing inorganic nanoparticles, vigorous anti-bacterial activity will be achieved in even lower concentration though higher stability in supreme conditions. In present scenario, interest of using nanoparticles for antibacterial packaging is increasing day to day due to its better results. So, it is a form of "active packaging" which contacts inside edible food material or to obstruct the growth of microbial population on the surface of food [36]. Requisition of nano-composites, an active substance for packaging plus coating material also used to enhance packaging of food commodity. Several nanoparticles possessing anti-microbial properties named as titanium dioxide, metal oxide, chitosan, zinc oxide, silver, and copper [37]. The nano-sized anti-bacterial films are developed by inseminating the fillers into polymeric materials which collaboratively advantageous because of its barrier properties as well as structural integrity.

VII. SAFETY CONCERNS IN FOOD NANOTECHNOLOGY

Inspite of nanotechnological advantages in food industries, safety concerns related to nanomaterials cannot be forsake. However, fast development of nanotechnology applications in food sector also raised various issues such as environmental, safety, policy, regulatory, including ethical. Several researchers considered about safety concerns connected with nanomaterials and also giving importance on the probability of nanoparticles emigrate from food packaging material to foods, likewise bad impact on human health. As well, materials used in food are usually comes under generally recognized as safe (GRAS), several studies had been completed to estimate the chances of their nanoscale as nanoparticles properties, differ from macro-particles. Furthermore, the tiny sizes of nanoparticles could raise bioaccumulation likelihood among tissues and organs in human body [38].Suppose that, SiO_2 (Silica) nanoparticles are utilized as anti-caking agent moreover, exposing with silica may be

cytotoxic among human lung cells [39]. Some countries have implemented specific regulations or guidelines for nanomaterials in food, while others are still in the process of establishing appropriate frameworks. Consumers should remain aware of these safety concerns, and food manufacturers must prioritize the rigorous testing and risk assessment of nanomaterials used in food products to ensure their safety and compliance with regulations. As new research emerges, the understanding of nanotechnology's safety implications in the food industry will continue to evolve.

VIII. CONCLUSION

Nanotechnology has emerged as a game-changer in the food industry, with its role in food processing and packaging revolutionizing the way we produce, preserve, and consume food. Food items now have a longer shelf life, better texture, taste, and nutritional content by the usage of nanocarriers, nanoencapsulations, and nanosensors, as well as protection from microbial infestations and spoiling. Incorporating nanosensors for real-time monitoring and improving mechanical strength, barrier characteristics, and antibacterial capabilities has allowed for the creation of "smart" and "active" packaging systems. In order to fully utilize the potential of nanotechnology and its transformative impact on the food sector as we move forward, careful consideration of safety and sustainability is essential.Nanotechnology has emerged as a highly promising and transformative technology in the food sector, offering exciting opportunities to improve food quality, safety, and nutrition. By manipulating matter at the nanoscale, nanotechnology can enhance food packaging, prolong shelf life, and detect contaminants more effectively. Additionally, the development of nano-sized nutrients and additives can enhance the nutritional value of food products. However, careful consideration of safety and regulation is crucial to ensure responsible implementation and public acceptance of this emerging technology. With its potential to revolutionize food production and consumption, nanotechnology stands as a key player in shaping the future of the food industry.

REFERENCES

[1] Vinatier, C., Mrugala, D., Jorgensen, C., Guicheux, J., & Noël, D. (2009). Cartilage engineering: a crucial combination of cells, biomaterials and biofactors. *Trends in biotechnology*, *27*(5), 307-314.
[2] Shrivastava, S., & Dash, D. (2012). Nanotechnology in food sector and agriculture. *Proceedings of the National Academy of sciences, India section B: Biological sciences*, *82*, 29-35.
[3] Ravichandran, R.; Sasi Kala, P. (2006). Nanoscience and nanotechnology: perspectives and overview. *School Sci.*43–49.
[4] The Eleventh ASEAN Food Conference; 21–23 Oc-tober (2009); Bandar Seri Begawan, Brunei Darussalam.
[5] Nickols-Richardson, S.M.; Piehowski, K.E. (2008). Nanotechnology in nutritional sciences.*Minerva Biotechnology*. 20, 17–126.
[6] Ravichandran, R. (2009). Nanotechnology-based drug delivery systems. *NanoBiotechnology*, *5*(1-4), 17-33.
[7] Degant, O., &Schwechten, D. (2002). Wheat flour with increased water binding capacity and process and equipment for its manufacture. *German Patent DE10107885A1*.
[8] Watanabe, J., Iwamoto, S., & Ichikawa, S. (2005). Entrapment of some compounds into biocompatible nano-sized particles and their releasing properties. *Colloids and Surfaces B: Biointerfaces*, *42*(2), 141-146.
[9] Chen, L., Remondetto, G. E., &Subirade, M. (2006). Food protein-based materials as nutraceutical delivery systems. *Trends in Food Science & Technology*, *17*(5), 272-283.
[10] Awuchi, C. G., Twinomhwezi, H., Choudghal, S., Khan, M. G., Yezdani, U., &Akram, M. V. (2020). Nanotechnology Application in Food Science and Nutrition and Its Safety Issues; a Review. *Adv. Bioresearch*, 11.

[11] Nanotechnology in agriculture and food, available at http://www.nanoforum.org.

[12] Yih, T. C., & Al-Fandi, M. (2006). Engineered nanoparticles as precise drug delivery systems. *Journal of cellular biochemistry*, *97*(6), 1184-1190.

[13] Ligler, F. S., Taitt, C. R., Shriver-Lake, L. C., Sapsford, K. E., Shubin, Y., & Golden, J. P. (2003). Array biosensor for detection of toxins. *Analytical and bioanalytical chemistry*, *377*, 469-477.

[14] El-Temsah, Y. S., &Joner, E. J. (2012). Ecotoxicological effects on earthworms of fresh and aged nano-sized zero-valent iron (nZVI) in soil. *Chemosphere*, *89*(1), 76-82.

[15] Nile, S. H., Baskar, V., Selvaraj, D., Nile, A., Xiao, J., & Kai, G. (2020). Nanotechnologies in food science: applications, recent trends, and future perspectives. *Nano-micro letters*, *12*, 1-34.

[16] Chau, C. F., Wu, S. H., & Yen, G. C. (2007). The development of regulations for food nanotechnology. *Trends in Food Science & Technology*, *18*(5), 269-280.

[17] Madene, A., Jacquot, M., Scher, J., &Desobry, S. (2006). Flavour encapsulation and controlled release–a review. *International journal of food science & technology*, *41*(1), 1-21.

[18] Estevinho, B. N., & Rocha, F. (2017). A key for the future of the flavors in food industry: nanoencapsulation and microencapsulation. In *Nanotechnology applications in food* (pp. 1-19). Academic Press.

[19] Quintanilla, M.X., Camacho, B.H., Mera, L.S., & Torres. (2010). Nanoencapsulation: a new trend in food engineering processing. *Food Engineering Reviews*, 2(1), 39–50.

[20] Gharsallaoui, A., Roudaut, G., Chambin, O., Voilley, A., &Saurel, R. (2007). Applications of spray-drying in microencapsulation of food ingredients: An overview. *Food research international*, *40*(9), 1107-1121.

[21] McClements, D. J. (2015). Nanoscale nutrient delivery systems for food applications: improving bioactive dispersibility, stability, and bioavailability. *Journal of food science*, *80*(7), N1602-N1611.

[22] Shegokar, R., & Müller, R. H. (2010). Nanocrystals: industrially feasible multifunctional formulation technology for poorly soluble actives. *International journal of pharmaceutics*, *399*(1-2), 129-139.

[23] Valdés, M. G., Valdés González, A. C., GarcíaCalzón, J. A., &Díaz-García, M. E. (2009). Analytical nanotechnology for food analysis. *MicrochimicaActa*, *166*, 1-19.

[24] McClements, D. J. (2015). Nanoscale nutrient delivery systems for food applications: improving bioactive dispersibility, stability, and bioavailability. *Journal of food science*, *80*(7), N1602-N1611.

[25] Ezhilarasi, P. N., Karthik, P., Chhanwal, N., &Anandharamakrishnan, C. (2013). Nanoencapsulation techniques for food bioactive components: a review. *Food and Bioprocess Technology*, *6*, 628-647.

[26] Bratovcic, A., Odobasic, A., Catic, S., &Sestan, I. (2015). Application of polymer nanocomposite materials in food packaging. *Croat Journal Food Science Technology* 7 (2): 86–94.

[27] Zhu, F. (2021). Buckwheat proteins and peptides: Biological functions and food applications. *Trends in Food Science & Technology*, *110*, 155-167.

[28] Nakagawa, K. (2014). Nano-and microencapsulation of flavor in food systems. *Nano-and Microencapsulation for Foods*, 249-271.

[29] Yang, R., Zhou, Z., Sun, G., Gao, Y., Xu, J., Strappe, P., ...& Ding, X. (2015). Synthesis of homogeneous protein-stabilized rutinnanodispersions by reversible assembly of soybean (Glycine max) seed ferritin. *RSC Advances*, *5*(40), 31533-31540.

[30] Ottaway, P. B. (2009). Nanotechnology in supplements and foods–EU concerns. *Nutraceuticals International*, 1.

[31] Ozturk, A. B., Argin, S., Ozilgen, M., and McClements, D. J. (2015). Formation and stabilization of nanoemulsion-based vitamin E delivery systems using natural biopolymers: whey protein isolate and gum. *Food Chemistry*. 188, 256–263.

[32] Yan, S. S., & Gilbert, J. M. (2004). Antimicrobial drug delivery in food animals and microbial food safety concerns: an overview of in vitro and in vivo factors potentially affecting the animal gut microflora. *Advanced drug delivery reviews*, *56*(10), 1497-1521.

[33] Sari, P., Mann, B., Kumar, R., Singh, R. R. B., Sharma, R., Bhardwaj, M., et al. (2015). Preparation and characterization of nanoemulsion encapsulating curcumin. *Food Hydrocol*. 43, 540–546.

[34] Mihindukulasuriya, S. D. F., & Lim, L. T. (2014). Nanotechnology development in food packaging: A review. *Trends in Food Science & Technology*, *40*(2), 149-167.

[35] Sorrentino, A., Gorrasi, G., &Vittoria, V. (2007). Potential perspectives of bio-nanocomposites for food packaging applications. *Trends in food science & technology*, *18*(2), 84-95.

[36] Soares, N. F. F., Silva, C. A. S., Santiago-Silva, P., Espitia, P. J. P., Gonçalves, M. P. J. C., Lopez, M. J. G., et al. (2009). "Active and intelligent packaging for milk and milk products," in Engineering Aspects of Milk and Dairy Products, eds J. S. R. Coimbra and J. A. Teixeira (New York, NY: CRC Press), 155–174.

[37] Bradley, E. L., Castle, L., & Chaudhry, Q. (2011). Applications of nanomaterials in food packaging with a consideration of opportunities for developing countries. *Trends in food science & technology*, *22*(11), 604-610.

[38] Tam, V. W., & Fung, I. W. (2011). Tower crane safety in the construction industry: A Hong Kong study. *Safety science*, *49*(2), 208-215.

[39] Athinarayanan, J., Periasamy, V. S., Alsaif, M. A., Al-Warthan, A. A., &Alshatwi, A. A. (2014). Presence of nanosilica (E551) in commercial food products: TNF-mediated oxidative stress and altered cell cycle progression in human lung fibroblast cells. *Cell biology and toxicology*, *30*, 89-100.