

Extending the Shelf Life of *Tilapia* Mince by Zinc Oxide Nanoparticle – A Precursor of Value-Added Fishery Product

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Authors' contributions

This work was carried out in collaboration among all authors. Author KP collected major of the literatures cited here and wrote the first draft of the manuscript under the guidance of authors SC and SN finally prepared and arranged the final manuscript, modified and refined as per the journal guidelines. Authors PM and FHR helped in final refinement of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Zinc deficiency is associated with impaired growth, poor immune function and also adverse pregnancy outcomes. The main strategies to alleviate mineral deficiencies are food diversification, food fortification or supplementation. Recently, there is a growing interest on the metal oxide nanoparticles owing to its various aspects such as bactericidal agents, destruction of carcinogenic cells and drug delivery applications. Fortification of zinc can be done with Zinc oxide (ZnO), currently listed as a generally recognized as safe (GRAS) material by the Food and Drug Administration. Due to the high antibacterial activity, chemical stability and solubility, nano-ZnO shows great interests in the application in fields of food additives, packing and agriculture, and biomedicine. The minced fish technology minimizes wastes, efficiently uses existing resources, helps in production of new versatile and nutritious foods and provides economic advantage to both the producer and

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consumer. Minced meat is used as a raw material for preparation of number of value-added products such as fish sausage, cakes, cutlets, patties, balls, pastes, texturized products, etc. Tilapia, an economically important food fish, is hardy and easy-to-grow, white-fleshed, mild-flavored and soothing palatability, thus regarded as a successful farmed fish and raw material of fish mince and subsequently surimi. During frozen or refrigerated storage, fish mince undergoes degradation; significant deterioration of sensory quality and loss of nutritional value have been detected as a result of changes in the protein and lipid fractions, formation of amines (volatile and biogenic) and hypoxanthine and changes in the physical properties of the muscle. The use of Zinc nanoparticles may be an efficient way of extending shelf life and food safety through the inhibition of spoilage and pathogenic bacteria without altering the nutritional quality of raw materials and food products due to broad-spectrum antibacterial activity of ZnO Np against pathogenic bacteria such as *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *E. coli O157:H7*, *Salmonella enteritidis*, *Salmonella typhimurium*, *Pseudomonas fluorescens*, *Campylobacter jejuni*, *Pseudomonas aeruginosa* and *Listeria monocytogenes*. Thus, after reviewing a wide range of literatures, it can be projected that development of low-cost Zn Nano-particle fortified value-added fish product is the ultimate future to eradicate zinc deficiency and can be rational kick start to alleviate protein as well as zinc malnutrition.

Keywords: Zinc oxide nano particle; tilapia surimi; zinc deficiency; value-added fishery product; ZnO fortification.

1. INTRODUCTION

Modernization of fish processing equipment and new technologies has opened the way for increasing utilization of underutilized, low valued fishes through minced meat technology. Minced meat is the flesh separated from skin, bones, scales and fins of fish. It is used as an intermediate raw material for the preparation of different types of products which have good demand. It is an inexpensive source of quality protein for food provided it could be incorporated by suitable methods into acceptable products [1]. Minced fish represents a significant advance in an effort aimed at improving utilization of fish proteins in human food [2]. The minced fish technology minimizes wastes, efficiently uses existing resources, helps in production of new versatile and nutritious foods and provides economic advantage to both the producer and consumer. It is used as a raw material for preparation of number of value-added products such as fish sausage, cakes, cutlets, patties, balls, pastes, texturized products, etc. Increased knowledge gives the potential idea to develop and produce products with desirable qualities and enables researchers to fortify the mince with trace elements like Zinc.

Due to presence of high-quality protein containing well-balanced highly digestible essential amino acids, freshwater fish are regarded as rich animal protein source. Several investigations have been done on the quality of the mince of fresh water fish like silver carp,

tilapia and Thai pangas for the manufacture of surimi [3]. For preparation of mince, the fish should have good gel strength making an elastic texture, good taste, whiter appearance, the availability as well as abundant supply of fish throughout the year and lower price.

2. TILAPIA AS RAW MATERIAL FOR MINCE

Tilapia is an economically important food fish that has proved to be a successful aquaculture species. The species is hardy and easy to grow, white-fleshed, mild-flavored and appeal to the palate of consumers. Nile tilapia (*Oreochromis niloticus*) is a notable variety and is native to Lake Albert and rivers of West Africa [4]. Over 4000 years ago, the depiction on bas-relief from an Egyptian tomb dating back reveals the aquaculture practice of Nile tilapia (*Oreochromis niloticus*) in ornamental ponds of ancient Egypt. Later on, Nile tilapia was introduced to Thailand in 1965, and from Thailand they were sent to the Philippines and rest of the South East Asian countries [5]. Because of their rapid growth and palatability, tilapia is one of the most important and widely grown groups of farmed fish.

Chakraborty et al. [6] successfully demonstrated the usefulness of tilapia for production of fish mince and subsequently surimi. The proximate composition of tilapia was reported to be moisture-78.5%, protein-18.03%, ash-2.01% and fat-0.88% [6]. A high-protein content and low-fat

content is very important to get good quality gel emulsion and analog products [6]. Therefore, tilapia with similar proximate values can be opted as a suitable species for preparation of mince.

3. ZINC OXIDE NANO-PARTICLES (ZNO NPS)

Recently, there is a growing interest on the metal oxide nano-particles owing to its various aspects such as bactericidal agents [7], destruction of carcinogenic cells and drug delivery applications [8]. The Zinc oxide nanoparticle (ZnO NPs) has a wide area of applications in various fields such as active laser medium and luminescence for fluorescent bulbs as well as in antimicrobial activities [9]. It has various other advantages such as non-toxicity, natural abundance and good photocatalysis [10]. Hussein et al. [11] reported that ZnO NPs act as a promising material in reducing health risk due to diabetic complications and insulin resistance in experimental diabetes. Zinc oxide (ZnO) is one of the five zinc compounds that are currently listed as GRAS (Generally recognized as safe) by the FDA [12]. Moreover, toxicity mechanisms can significantly be controlled by inhibiting immune cells by action of ZnO NP [13].

Due to environmental compatibility of earlier and quick preparations, ZnO NPs have high catalytic organic transformations [14]. In the field of electrochemistry, photodynamic effect of sensors can be varied by the successful use of ZnO NPs [15]. According to the researchers The ZnO NPs were considered as one of the best metal nanoparticles in the world which attracted the attention towards the optical and electrochemical properties that were widely studied [16]. Mao et al. [17] reported the efficient activity of ZnO NPs to detect few of the toxic gases present in environment. It also has a potential application in preparation of functional food to tackle Zn deficiency in undernourished populations.

4. ZINC OXIDE NANO-PARTICLE FORTIFICATION IN FUNCTIONAL FOODS

Functional food conveniently provides health benefits beyond nutrition which means, the variety of components in functional foods, both nutrients and non-nutrients, affect a range of body functions that are relevant to a state of well-being and health and reduce the risk of a disease

[18]. Singh [19] reported that the nanoscience and nanotechnology can successfully develop functional foods by inclusion of bioactive compounds without affecting the sensory perception of the consumer and improving the uptake of certain components. Iron (Fe) and zinc (Zn) deficiencies are major global public health problems. They are particularly common in developing countries and are estimated to affect more than two billion people worldwide [20].

Zinc deficiency does not result in one specific outcome or manifestation, but in many diverse biochemical changes [21]. Zinc deficiency is associated with impaired growth, poor immune function and also adverse pregnancy outcomes [22]. Thus, it is an important cause of morbidity especially in young children in developing countries. Worldwide, the main cause of these deficiencies is low dietary bioavailability of iron and zinc from plant-based diets [23]. The main strategies to alleviate mineral deficiencies are food diversification, food fortification or supplementation [24].

Raya et al. [25] performed Zinc deficient rats' model by nourishing on zinc deficient diet for five weeks to acquire zinc deficiency. Three levels nano zinc oxide Fortified Biscuits (13.5 ppm, 27 ppm and 54 ppm) were prepared to be compared with bulk form of zinc oxide for the zinc deficient rats. Nano zinc treated rats exhibited rapid enhancement of body growth rate, appetite and hair growth. According to Berekaa [26], during the food processing, nano-particles have been applied to improve nutritional quality, flow properties, flavor, color and stability or to increase shelf life. Thus, nanotechnology might help in development of healthier food with lower sugar, fat and salt content to overcome many food-related diseases as preferred by present day health conscious consumers.

5. ZnO-NP APPLICATION IN FOOD PROCESSING, SHELF LIFE EXTENSION AND PACKAGING

Due to the high antibacterial activity, chemical stability and solubility, nano-ZnO shows great interests in the application in fields of food additives, packing and agriculture, and biomedicine [27]. In food sector, one of the earliest commercial applications of nanotechnology is in food packaging industry. According to Berekaa [26], nanoparticles can be

incorporated into the food packaging materials to increase shelf life due to antimicrobial characteristics and keep it safe for human consumption. According to Silvestre et al. [28], novel and efficient polymeric materials for food packaging developed with nanotechnology can provide solutions to food industry challenges related to product safety and materials performance as well as economic and environmental advantages. According to Chaudhry et al. [29], food packaging materials developed with nanotechnology are the largest category of current nanotechnology applications for the food sector.

5.1 Synthesis of ZnO-nanoparticles

According to Mirzaei and Darroudi [30], Zinc oxide (ZnO) exists within the earth crust as a mineral zincite, while most of it that is used commercially is produced through synthetic methods. The ZnO NPs can be synthesized by the following methods.

5.2 Chemical Synthesis of ZnO-Nanoparticles

Chemical synthesis of ZnO [4] and mechanochemical methods [31]. Each of these methods have their own disadvantages in stability and self-aggregation. Hence, green synthesis of metal and metal oxide nanoparticles [32] gained importance. Although, most chemical synthesis methods lead to the presence of some toxic chemical species adsorbed on the surface which may have adverse effects on the environment [33], Hussein et al. [34] chemically synthesized ZnO-NPs using environmental benign biodegradable hydroxyl ethyl cellulose (HES) in presence of potassium hydroxide, where the biodegradable-biocompatible HES was used as stabilizing and directing agent.

5.3 Biological Synthesis

Biological Synthesis or Green synthesis of nanoparticles makes use of environmental-friendly, non-toxic and safe reagents. The natural materials and biopolymers are used to synthesize the ZnO-NPs for the utilization of environmental source [35]. Plant leaf extract [36], bacteria [37], fungi [38] and algae [39] offers varied advantages of eco-friendliness and compatibility for pharmaceutical and different medicinal applications, whereas noxious chemicals are not used for the synthesis protocol.

6. ROLE OF ZnO-NPs AS SHELF LIFE ENHANCER IN MINCED MEAT UNDER REFRIGERATED STORAGE

The proximate composition of raw material influences the proximate composition of the mince as well surimi prepared from it. Proximate composition is such a unique attribute of fish which varies due to species, age, sex, diet, catching season and environment [40]. Chakraborty et al. [6] opined that the selected fish should have 70% myoproteins with low amount of water-soluble protein and lipid content for maintaining a good nutritional quality of the final product. Tilapia with moisture (78.5%), protein (18.03%), ash (2.01%) and fat (0.88%) was reported to be a suitable species for fish mince as well as surimi preparation [6].

During frozen or refrigerated storage, fish mince undergoes degradation of both protein and fat. Consequently, change in moisture content is also observed. Natural enzymes present in the fish generate autolytic changes in it that produce amines, amino acids and glucose for bacterial growth. Bacteria convert the nitrogenous compounds such as ammonia, aldehyde, hydrogen sulfide and indole into various other derivatives under putrefaction [41]. Significant deterioration of sensory quality and loss of nutritional value have been detected as a result of changes in the protein and lipid fractions, formation of amines (volatile and biogenic) and hypoxanthine and changes in the physical properties of the muscle [42]. Such biochemical changes are undesirable and require application of several preservation techniques including use of preservatives and low temperature preservation. The use of Zinc nanoparticles may be an efficient way of extending shelf life and food safety through the inhibition of spoilage and pathogenic bacteria without altering the nutritional quality of raw materials and food products.

Zhang et al. [43] studied the characterization of micro emulsion nano films based on tilapia fish skin gelatin and ZnO nanoparticles incorporated with ginger essential oil for packaging application which resulted strong anti-bacterial activity against food spoilage bacteria like *psychrotrophs*, *mesophiles* and *Lactobacillus* spp. (LAB) *in situ* and food pathogenic bacteria such as *Escherichia coli* and *Listeria monocytogenes in vitro*. As far as the microbiological quality of the raw material is concerned, fresh tilapia muscle was reported to

Table 1. Synthesis methods of ZnO-nanoparticles

Method	Precursor	Solvent	Size (nm)	Shape	Source
Coprecipitation Technique	Zinc acetate	Double distilled wate	80 (length), 30–60 (diameter)	Nanorod	[44]
Microwave Decomposition	Zinc acetate dehydrate	1-Butyl-3-methylimidazolium bis (trifluoromethylsulfonyl) imide [bmim][NTf2]	37–47	Sphere	[45]
Hydrothermal Process	Zinc acetate dihydrate	Polyvinylpyrrolidone (PVP)	5 μm (length), 50–200 (diameter)	Nanorod	[46]
Wet chemical Method	Zinc nitrate hexahydrate	Sodium hydroxide (NaOH) as precursors and soluble starch as stabilizing agent	20–30	Acicular	[47]
Sol–gel method in gelatin media	Zinc nitrate	Distilled water and gelatine as substrate	30–60	Circular and hexagonal	[48]

Table 2. Various Natural and microbial sources and morphological studies of ZnO-NP

Sl. No	Natural and microbial sources	Nanoparticle shape	Size (nm)
1	<i>O. basilicum</i>	Hexagonal	50
2	<i>C. rhizome</i>	Hexagonal	2.9
3	<i>N. lappaceum</i>	Spherical	20
4	Aloe vera	Spherical	45
5	<i>C. sinensis</i>	Hexagonal	16
6	<i>C. roseus</i>	Spherical	23
7	Banana	Hexagonal	46
8	<i>B. flabellifer</i>	Rod	55
9	<i>P. amboinicus</i>	Spherical	8
10	<i>P. hysterothorus</i>	Hexagonal	27
11	<i>Candida albicans</i>	Hexagonal	25
12	<i>RhodococcuspyridinivoransNT 2</i>	Hexagonal	120
13	<i>S. ureilytica</i>	Sunflower	175
14	Plasmid DNA	Tetrapod	32
15	Amino acids	Hexagonal	16
16	<i>S. myriocystum</i>	Spherical	36
17	<i>S. muticum</i>	Hexagonal	37
18	Egg white	Hexagonal	16
19	<i>Aeromonas hydrophila</i>	Spherical	57.3
20	<i>Lactobacillus plantarum</i>	Spherical and Hexagonal	7–19

show a Total Plate Count (TPC) value of 3.2×10^5 /gm of sample [6]. International Commission on Microbiological Specifications for Foods [49] recommended that an increase of TPC up to levels exceeding the value of 6 log cfu/gm is regarded as microbiological spoiled fish muscle, not fit for human consumption.

Table 3. Algae sources of zinc oxide-nanoparticals

Sl no	Name of algae
1	Marine macroalgae
2	<i>Caulerpa peltata</i>
3	<i>Hypnea Valencia</i>
4	<i>Sargassum myriocystum</i>
5	<i>Sargassum muticum</i>

Table 4. Fungi sources of zinc oxide-nanoparticals

Sl no	Name of fungi
1	<i>Aspergillus fumigates</i>
2	<i>Aspergillus aeneus</i>
3	<i>Fusarium spp</i>

ZnO is currently listed as a generally recognized as safe (GRAS) material by the Food and Drug Administration [12]. According to Mostafa [50], ZnO NPs act as a food additive and it is the most commonly used zinc source in the fortification of cereal based foods. Espitia et al. [51], reported that ZnO has antimicrobial properties *in vitro*

against food borne pathogens and spoilage bacteria. Nano-sized particles of ZnO have more pronounced antimicrobial activities than large particles due to the small size (< 100 nm). ZnO has been incorporated into the linings of food cans in packages for meat, fish, corn and peas to preserve colors and to prevent spoilage. According to Kim et al. [52], nano-scale materials have emerged up as novel antimicrobial agents due to their high surface area to volume ratio and the unique chemical and physical properties which allow for better interaction with bacteria.

Seil and Webster, [53] opined that when particle size is reduced to the nanometer range, the nano-sized ZnO can interact with bacterial surface and/or with the bacterial core by entering inside the cell, followed by exhibiting distinct bactericidal mechanisms. ZnO-NPs are reported in several studies as non-toxic to human cells [54]. This aspect necessitated their usage as antibacterial agents, noxious to microorganisms, and hold good biocompatibility to human cells [55]. Ravisakar and Jamuna [56] studied antibacterial activities of ZnO-Nps against broad-spectrum pathogenic bacteria such as *Staphylococcus aureus*, *Bacillus subtilis*, *Escherichia coli*, *E. coli O157:H7*, *Salmonella enteritidis*, *Salmonella typhimurium*, *Pseudomonas fluorescens*, and *Listeria monocytogenes*. Xie et al. [57] investigated the antibacterial effect of ZnO-nanoparticles on *Campylobacter jejuni* for cell growth inhibition

and inactivation. The results showed that *C. jejuni* was extremely sensitive to the treatment with ZnO-nanoparticles. Pawar et al. [58], reported zinc oxide-nanoparticles inhibit the growth of leading food borne pathogenic bacteria, *Pseudomonas aeruginosa*.

7. CONCLUSION

Food fortification, the addition of micronutrients to processed foods, is very instrumental for relatively rapid improvements in the micronutrient status of a population. Fortification of zinc is done in various forms which include zinc sulfate, zinc oxide (ZnO), zinc acetate and zinc gluconate [59] among which ZnO is currently listed as a generally recognized as safe (GRAS) material by the Food and Drug Administration [60]. Hence, fortification of food using ZnO may be a good solution to overcome Zn deficiency and to improve the nutritional status of the food. Moreover, literatures reflect that among different food alternatives, fish has proven to be a good choice for Zn fortification. Due to the high antibacterial activity, chemical stability and solubility, nano-ZnO shows great interests in the application in fields of food additives, packing and agriculture, and biomedicine. Several researches are going on for successful fortification of fish mince, especially Tilapia mince, with Zn and to improve the shelf life of the mince which is the ultimate precursor of a number of value-added fish and fishery products such as fish sausage, cakes, cutlets, patties, balls, pastes and texturized products. Thus, development of low-cost Zn-Nano particle fortified value-added fish product is the ultimate future to eradicate zinc deficiency and can be rational kick start to alleviate protein as well as zinc malnutrition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

- Gharibzahedi SMT, Roohinejad S, George S, Barba FJ, Greiner R, Barbosa-Cánovas GV, Mallikarjunan K. Innovative food processing technologies on the transglutaminase functionality in protein-based food products: Trends, opportunities and drawbacks. Trends in Food Science & Technology. 2018;75:194-205.
- Weinberg-Sehayek N, Weinberg A. U.S. Patent No. 9,883,690. Washington, DC: U.S. Patent and Trademark Office; 2018.
- Chowdhury S, Sarkar S, Dora KC. Quality changes in fish cakes prepared from washed Silver carp mince under frozen storage (-20°C). Indian Journal of Nutrition and Dietetics. 2009;46(2): 78-85.
- Lowe-McConnell RH. Broad characteristics of the ichthyofauna: General characteristics of the ichthyofauna. In: Biology and Ecology of African Freshwater Fishes, (Eds. Leveque C, Bruton M.N. and Ssentongo, G.M.) ORSTOM, Paris. 1988; 93-110.
- Rakocy JE. Cultured aquatic species information programme. *Oreochromis niloticus*. FAO Fisheries and Aquaculture Department, Rome; 2005. Available: www.fao.org/fishery/culturedspecies/Oreochromis_niloticus/en (Consulted: 26 February 2012).
- Chakraborty A, Dora KC, Sarkar S, Chowdhury S. Shelf-life of surimi prepared from tilapia (*Oreochromis niloticus*) during frozen storage. Asian Journal of Animal Science. 2009;4(1):18-21.
- Faramarzi MA, Sadighi A. Insights into biogenic and chemical production of inorganic nanomaterials and nanostructures. Advances in Colloid and Interface Science. 2013;189:1-20.
- Dubey P, Matai I, Kumar SU, Sachdev A, Bhushan B, Gopinath P. Perturbation of cellular mechanistic system by silver nanoparticle toxicity: Cytotoxic, genotoxic and epigenetic potentials. Advances in colloid and interface science. 2015;221:4-21.
- Maryanti E, Damayanti D, Gustian I. Synthesis of ZnO nanoparticles by hydrothermal method in aqueous rinses extracts of Sapindus rarak DC. Materials Letters. 2014;118:96-98.
- Mallika AN, Ramachandra Reddy A, Sowri Babu K, Reddy KV. Synthesis and optical characterization of aluminum doped ZnO nanoparticles. Ceramics International. 2014;40(8): 12171-12177.
- Hussein J, El-Naggar ME, Latif YA, Medhat D, El Bana M, Refaat E, Morsy S. Solvent-free and one-pot synthesis of silver and zinc oxide nanoparticles: activity toward cell membrane component and insulin signaling pathway in experimental

- diabetes. *Colloids and Surfaces B: Biointerfaces*. 2018a;170:76-84.
12. Jin T, Sun D, Su JY, Zhang H, Sue HJ. Antimicrobial efficacy of zinc oxide quantum dots against *Listeria monocytogenes*, *Salmonella enteritidis*, and *Escherichia coli* O157: H7. *Journal of Food Science*. 2009;74(1):M46-M52.
 13. Roy R, Das M, Dwivedi PD. Toxicological mode of action of ZnO nanoparticles: Impact on immune cells. *Molecular immunology*. 2015;63(2):184-192.
 14. Banerjee S, Payra S, Saha A, Sereda G. ZnO nanoparticles: A green efficient catalyst for the room temperature synthesis of biologically active 2-aryl-1, 3-benzothiazole and 1, 3-benzoxazole derivatives. *Tetrahedron Letters*. 2014; 55(40):5515-5520.
 15. Ozcelik BK, Ergun C. Synthesis of ZnO nanoparticles by an aerosol process. *Ceramics International*. 2014; 40(5):7107-7116.
 16. Salam HA, Sivaraj R, Venkatesh R. Green synthesis and characterization of zinc oxide nanoparticles from *Ocimum basilicum* L. var. *purpurascens* Benth.-Lamiaceae leaf extract. *Materials Letters*. 2014;131:16-18.
 17. Mao YZ, Ma SY, Li WQ, Xu XL, Gengzang DJ, Luo J, Cheng, L. Synthesis of porous spherical ZnO nanoparticles and measurement of their gas-sensing property. *Materials Letters*. 2014;134:80-83.
 18. Bigliardi B, Galati, F. Innovation trends in the food industry: The case of functional foods. *Trends in Food Science & Technology*. 2013;31(2):118-129.
 19. Singh H. Nanotechnology applications in functional foods; opportunities and challenges. *Preventive Nutrition and Food Science*. 2016;21(1):1.
 20. WHO/UNICEF/UNU, Who, U. UNU. Iron deficiency anemia: Assessment, prevention and control, a guide for programme managers. Geneva: World Health Organization; 2001.
 21. King JC. Zinc: An essential but elusive nutrient. *The American Journal of Clinical Nutrition*. 2011;94(2):679S-684S.
 22. International Zinc Nutrition Consultative Group. Assessment of the risk of zinc deficiency and options for its control. *Food and Nutrition Bulletin*. 2004;25:S91-S204.
 23. Zimmermann MB, Chaouki N, Hurrell RF. Iron deficiency due to consumption of a habitual diet low in bioavailable iron: A longitudinal cohort study in Moroccan children. *The American Journal of Clinical Nutrition*. 2005;81(1):115-121.
 24. Rafferty K, Walters G, Heaney RP. Calcium fortificants: Overview and strategies for improving calcium nutrition of the US population. *Journal of Food Science*. 2007;72(9):R152-R158.
 25. Raya SDHA, Hassan MI, Farroh KY, Hashim SA, Salaheldin TA. Zinc oxide nanoparticles fortified biscuits as a nutritional supplement for zinc deficient rats. *Journal of Nanomedicine Research*. 2016;4(00081):10-15406.
 26. Berekaa MM. Nanotechnology in food industry; advances in food processing, packaging and food safety. *International Journal of Current Microbiology and Applied Sciences*. 2015;4(5): 345-357.
 27. Sirelkhatim A, Mahmud S, Seeni A, Kaus NHM, Ann LC, Bakhori SKM, Mohamad D. Review on zinc oxide nanoparticles: Antibacterial activity and toxicity mechanism. *Nano-Micro Letters*. 2015; 7(3):219-242.
 28. Silvestre C, Duraccio D, Cimmino S. Food packaging based on polymer nanomaterials. *Progress in Polymer Science*. 2011;36(12):1766-1782.
 29. Chaudhry Q, Scotter M, Blackburn J, Ross B, Boxall A, Castle L, Aitken R, Watkins R. Applications and implications of nanotechnologies for the food sector. *Food Additives & Contaminants: Part A*. 2008;25(3):241-258.
 30. Mirzaei H, Darroudi M. Zinc oxide nanoparticles: Biological synthesis and biomedical applications. *Ceramics International*. 2017;43(1):907-914.
 31. Huang MH, Mao S, Feick H, Yan H, Wu Y, Kind H, Yang P. Room-temperature ultraviolet nanowire nanolasers. *Science*. 2001;292(5523):1897-1899.
 32. Song W, Wu C, Yin H, Liu X, Sa P, Hu J. Preparation of PbS nanoparticles by phase-transfer method and application to Pb²⁺ selective electrode based on PVC membrane. *Anal Letters*. 2008;41(15): 2844-2859.
 33. Vidya C, Hiremath S, Chandraprabha MN, Antony raj LMA, Gopal IV, Jain A, Bansal K. Green synthesis of ZnO nanoparticles by *Calotropis gigantea*. *International Journal of Current Engineering & Technology*. 2013;1:118-120.

34. Hussein J, El-Banna M, Razik TA, El-Naggar ME. Biocompatible zinc oxide nanocrystals stabilized via hydroxyethyl cellulose for mitigation of diabetic complications. *International Journal of Biological Macromolecules*. 2018b;107: 748-754.
35. Hosseini Shekarabi P, Hosseini SE, Soltani M, Kamali A, Valinassab T. A Comparative Study on physicochemical and sensory characteristics of minced fish and surimi from black mouth croaker (*Atrubuccanibe*). *Journal of Agricultural Science and Technology*. 2014;16(6): 1289-1300.
36. Nethravathi PC, Shruthi GS, Suresh D, Nagabhushana H, Sharma SC. *Garcinia xanthochymus* mediated green synthesis of ZnO nanoparticles: Photoluminescence, photocatalytic and antioxidant activity studies. *Ceramics International*. 2015; 41(7):8680-8687.
37. Jayaseelan C, Rahuman AA, Kirthi AV, Marimuthu S, Santhoshkumar T, Bagavan A, Rao KB. Novel microbial route to synthesize ZnO nanoparticles using *Aeromonas hydrophila* and their activity against pathogenic bacteria and fungi. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*. 2012;90:78-84.
38. Kundu D, Hazra C, Chatterjee A, Chaudhari A, Mishra S. Extracellular biosynthesis of zinc oxide nanoparticles using *Rhodococcus pyridinivorans* NT2: multifunctional textile finishing, biosafety evaluation and in vitro drug delivery in colon carcinoma. *Journal of Photochemistry and Photobiology B: Biology*. 2014;140:194-204.
39. Azizi S, Ahmad MB, Namvar F, Mohamad R. Green biosynthesis and characterization of zinc oxide nanoparticles using brown marine macroalga *Sargassum muticum* aqueous extract. *Materials Letters*. 2014;116:275-277.
40. Boran G, Karaçam H. Seasonal changes in proximate composition of some fish species from the Black Sea. *Turkish Journal of Fisheries and Aquatic Sciences*. 2011;11(1):1-5.
41. Sudalayandi K, Manja. Efficacy of lactic acid bacteria in the reduction of trimethylamine-nitrogen and related spoilage derivatives of fresh Indian mackerel fish chunks. *African Journal of Biotechnology*. 2011;10(1):42-47.
42. Aubourg SP. Fluorescence study of the pro-oxidant effect of free fatty acids on marine lipids. *Journal of the Science of Food and Agriculture*. 2001;81(4):385-390.
43. Zhang L, Liu A, Wang W, Ye R, Liu Y, Xiao J, Wang K. Characterisation of microemulsion nanofilms based on *Tilapia* fish skin gelatin and ZnO nanoparticles incorporated with ginger essential oil: Meat packaging application. *International Journal of Food Science & Technology*. 2017;52(7):1670-1679.
44. Bhadra P, Mitra MK, Das GC, Dey R, Mukherjee S. Interaction of chitosan capped ZnO nanorods with *Escherichia coli*. *Materials Science and Engineering: C*. 2011;31(5):929-937.
45. Jalal R, Goharshadi EK, Abareshi M, Moosavi M, Yousefi A, Nancarrow P. ZnO nanofluids: Green synthesis, characterization, and antibacterial activity. *Materials Chemistry and Physics*. 2010; 121(1-2):198-201.
46. Lepot N, Van Bael MK, Van den Rul H, D'Haen J, Peeters R, Franco D, Mullens J. Synthesis of ZnO nanorods from aqueous solution. *Materials Letters*. 2007;61(13): 2624-2627.
47. Premanathan M, Karthikeyan K, Jeyasubramanian K, Manivannan G. Selective toxicity of ZnO nanoparticles toward Gram positive bacteria and cancer cells by apoptosis through lipid peroxidation. *Nanomedicine: Nanotechnology, Biology and Medicine*. 2011;7(2):184-192.
48. Zak AK, Majid WA, Darroudi M, Yousefi R. Synthesis and characterization of ZnO nanoparticles prepared in gelatin media. *Materials Letters*. 2011;65(1):70-73.
49. ICMSF (International Commission on Microbiological Specifications for Foods). *Micro-organisms in Foods*, Toronto, Uni. Toronto Press; 1988.
50. Mostafa AA. Antibacterial activity of zinc oxide nanoparticles against toxigenic *Bacillus cereus* and *Staphylococcus aureus* Isolated from Some Egyptian Food. *International Journal of Microbiological Research*. 2015;6(2):145-154.
51. Espitia PJP, Soares NDFF, Teófilo RF, dos Reis Coimbra JS, Vitor DM, Batista RA, Medeiros EAA. Physical-mechanical and antimicrobial properties of nanocomposite films with pediocin and ZnO

- nanoparticles. Carbohydrate Polymers. 2013;94(1):199-208.
52. Kim JS, Kuk E, Yu KN, Kim JH, Park SJ, Lee HJ, Kim YK. Antimicrobial effects of silver nanoparticles. Nanomedicine: Nanotechnology, Biology and Medicine. 2007;3(1):95-101.
53. Seil JT, Webster TJ. Antimicrobial applications of nanotechnology: Methods and literature. International Journal of Nanomedicine. 2012;7:2767.
54. Colon G, Ward BC, Webster TJ. Increased osteoblast and decreased Staphylococcus epidermidis functions on nanophase ZnO and TiO₂. Journal of Biomedical Materials Research Part A. 2006;78(3):595-604.
55. Padmavathy N, Vijayaraghavan R. Enhanced bioactivity of ZnO nanoparticles—An antimicrobial study. Science and Technology of Advanced Materials. 2008;9(3):035004.
56. Ravishankar Rai, V, Jamuna Bai A. Nanoparticles and their potential application as antimicrobials. A Méndez-Vilas A, editor. Mysore: Formatex; 2011.
57. Xie Y, He Y, Irwin PL, Jin T, Shi X. Antibacterial activity and mechanism of action of zinc oxide nanoparticles against Campylobacter jejuni. Applied and Environmental Microbiology. 2011;77(7):2325-2331.
58. Pawar J, Shinde M, Chaudhari R, Singh EA. Semi-Solvo thermal synthesis and characterization of zinc oxide nanostructures against food borne pathogens. International Journal of Pharm Bio Science. 2017;8(2):311-315.
59. Allen LH. Zinc and micronutrient supplements for children. The American Journal of Clinical Nutrition. 1998;68(2):495S-498S.
60. FDA. Part 182—substances generally recognized as safe. Food and Drug Administration, Washington DC, USA; 2011.

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