Pak. j. sci. ind. res. Ser. B: biol. sci. 2023 **66B**(1) 65-73

Role of Silver Nanoparticles (AgNPs) in Food Surface Packaging

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(received July 7, 2021; revised January 1, 2022; accepted January 19, 2022)

Abstract. Reliance on processed food increased in the late 90s and the need for fresh food with a long shelf-life was felt according to the interest of consumers. Antibacterial effect of the papers used in food packaging extend the shelf-life of the products and food to keep them in healthier conditions. Binders used in paper coating provide a good nutrient medium for bacteria. As an antibacterial agent, AgNPs have been used significantly in health industry and in food storage and packaging, textile coatings and also in several environmental applications. They have also been used as antibacterial agent in medical device and in home appliance fumigation, as well as water treatment cotton fiber. AgNps from food packaging may be un-intentionally released into food and end up in the gastrointestinal tract. As a result, human exposure to AgNPs is increasing and it is critical to understand their negative effects. However, nano-particles migrating to food are not wholly studied by researchers. This review examines the most research findings on the use of AgNPs to protect food products against the most common food pathogens.

Keywords: silver nanoparticles, AgNPs, packaging, food packaging, food science, food industry

Introduction

Diets in the 1970's began to shift toward increased reliance upon processed foods, increased away from home intake and greater use of edible oils and sugar-sweetened beverages (Popkin *et al*., 2012). The working habits, women's increased jobs, lack of leisure, the rise in income and various other factors have led to fast food, convenience food and food from home. The need for convenient, portable and easy-to-prepare foods that reduce the trouble of food shopping and preparation of meals makes packaged food an indispensable component in a modern lifestyle (Ahmed *et al*., 2005). One of the main issues in food processing is the protection against foodborne diseases which still represent a global problem of public health. The Center for Disease Control and prevention (CDC) estimates that the impact of foodborne diseases in countries such as the United States results each year in 76 million sick people, 325,000 of which are hospitalized and 5000 die (Morris, 2011).

Nowadays, the packaging is an essential and primary element in modernizing trade in goods that preserve food and quality. It is a significant factor for protecting products that are packed contrary to external conditions that affect the safety and the food product quality. Packaging makes the transportation and storage of food products easier. It is suggested that the packaging is essential and it helps to improve production strategies to make proper packaging gradually, when packaging of products is done, some points must be kept in mind like Ultraviolet (UV) protection, transparency, environ-mental performance and a proper barrier to gas. For the reason of the packaging system of food products, the food industry has created new demands for the packaging market (Wyrwa and Barska, 2017).

The manufacture of packaging is an industry worldwide characterized by its internal diversity and all factors that affect the business situation and condition. The infrastructure and the packaging system specifications include the correct packaging of preservation items. According to the interest of the consumer, fresh food with a long shelf-life and a sufficient quality is needed. It contributes to the advancement of innovative techno-logies and ideas for the proper packaging of technological systems. Packaging, known as silent salesman, is the subject of much recent legislation (Imiru, 2017). How-ever, the nonverbal mark components of the kit are largely ignored by this legislation. The verbal elements of a package accurately represent the product's charac-teristics. A package on the other hand, can be used to

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strengthen or weaken the marketer's explicit oral statements. Colour, form, images and other aspects of package design frequently provide a statement and message about the product and its description. Maybe this non verbal assertion and statement is a subtle but important message.

Food items related to different brands are presented in various packaging colours, shapes, symbols, designs and messages. All these factors help to make these food products more attractive to the consumer. Also, these different packaging styles facilitate consumers about the types of packed products (Shiu *et al*., 2004). Other types of brands, their unique packaging style and the use of packaging for the transportation of products are making progress day by day all around the World. Several studies suggested that packaging helped the consumer decide when the consumer did not know much about consequences. Packaging style, message and formula, which are all mentioned, help acknowledge the effects (Prendergast and Marr, 1997). Food packaging shall be used as a barrier to avoid damaging external factors such as sun, pollutants and humidity. In recent decades, food packaging innovations have rapidly evolved with increased demand from customers for high quality food. Many new food packaging technologies have been launched with an active food packaging operation (Silayoi and Speece, 2007).

Food packaging shall be used as a barrier to avoid damages of external factors such as sun, pollutants and humidity. In recent decades, food packaging innovations have rapidly evolved with increased demand from customers for high quality food (Fernández *et al*., 2010). Many new food packaging technologies has been launched with an active food packaging operation (Silayoi and Speece, 2004). A good and active food packaging system can improve the effectiveness of the food shelf life by displaying functional properties like antimicrobial, antioxidant, water vapour barrier, maintenance or enhancement of food quality. Including active components like antioxidants antimicrobials, packaging goals can be achieved (Wells *et al*., 2007).

Active packaging system. Active packaging is essential and helpful to protect food quality *via* up-to-date systems. It is distinguished from an intelligent packaging system that mainly compliments the active packaging and its role in connecting and interacting with the buyer. These systems include physical, biological and chemical activities that improve the shelf life of food products and significantly improve the microbial safety of food and prevent it from any contamination. The new packaging system is opposite to the traditional packaging system. Active packaging extends the shelf life of food products and preserves their quality during the reaction with development and the internal atmosphere. So, dynamic packaging system is considered innovative in the field of food packaging (Wyrwa and Barska, 2017). The use of an active packaging system promotes the shelf life of food commodities by several factors.

- By protecting from the substances which absorb (scavengers) or release (emitters) gases or steam; physiological processes like the breathing of fresh vegetables and fruits are kept controlled; a chemical process, like oxidation of fats, are avoided; microbiological changes for the reason micro-organisms are handled; protect from insects that cause the infection.

Active packaging is an innovative concept in which products, packages and the environment work together to prolong the shelf life and increase the safety or sensory qualities, while maintaining the consistency of the product. This innovative thought has recently gained importance by implementing nano technological materials (such as nanoparticles and nano coating in the food industry) to provide fresh food items with long storage life (De Moura *et al*., 2012).

Table 1. Framework for packaging

Package design	Liking for package	Communication through package	Usability of package
Attraction of buyer	Brand	Colour	Ease of handling
Communication to the buyer	Country of origin	Symbol/Logo	Disposability
Convenience in handling	Colour connotation	Information about product	Moisture protection
Salability of product	Symbol connotation	Brand image	Protection from ultraviolet radiation
Green aspect	Size	Shape/Size	

Objectives. To analyze the most recent studies reported on protection of food products against the most common food pathogens by silver nanoparticles (AgNPs)-doped non-degradable and edible polymers.

Silver nanoparticles (AgNPs). Due to their unique properties, AgNPs have been used extensively in household utensils, the health care industry and in food storage, environmental and biomedical applications (An *et al*., 2008). The biological activity of AgNPs depends on factors including surface chemistry, size, size distribution, shape, particle morphology, particle composition, coating/capping, agglomeration and dissolution rate, particle reactivity in solution, efficiency of ion release and cell type, and the type of reducing agents used for the synthesis of AgNPs are a crucial factor for the determination of cytotoxicity (Fernández *et al*., 2010; Carlson *et al*., 2008).

Theoretical studies of bare and monolayer capped metal nanoparticles began in the early 1990s, with modeling of atomic scale structure and structural motifs (including the correct prediction of 5-fold symmetries) (Cleveland *et al*., 1997; Whetten *et al*., 1996), ligand-to-metal bonding (Hakkinen *et al*., 2006), and interligand bundling (Landman and Luedtke, 2004). Experimentally, however, little was known about the structure of molecular nanoparticles (mNPs) until the Kornberg Au102 structure was published in 2007. That structure found 5-fold symmetries in the metal core as well as the surprising fact that metal atoms were also found outside of the core, as an integral part of the ligand shell (Fig. 2), forming called "gold-sulphur staples" (Hakkinen *et al*., 2006). In retrospect, one may view these capping motifs as fragments of the metal-thiolate polymer decorating the metal core. The first structure of a silver mNP was published in 2013 by Yang *et al*. as different variants of the Ag44 arche type. Like gold, these silver structures also revealed 5-fold symmetries in the metal core as well as complex bonding at the core-shell interface. The 32 atom metal core has icosahedral symmetry and is composed of the hollow icosahedral inner shell surrounded by a dodecahedral outer shell. The approximately spherical core makes it tempting to consider the capping motif to be Ag2S5, but based on formal charges, the Ag4S5 capping unit should also be considered (Fig. 3).

Figure 3, Structure of a Na4Ag44(p-MBA)30 mNP. (a) Complete structure showing silver core and p-MBA ligands. (b) Space-filling view down a 3-fold axis. Note the ligand bundling, which opens gaps in the ligand layer. (c, d) The Ag32 excavated-dodecahedral core consists of a hollow 12-atom icosahedron (red) inside of a 20 atom dodecahedron (green). Eight atoms in the dodecahedron (light green) define a cube with the remaining Ag atoms (dark green) located in pairs above each face of that cube. (e) Sulphur atoms are arranged in a slightly distorted rhombicuboctahedron. (f) Six Ag2S5 units cap the dodecahedral core, to complete the inorganic structure. (g, h) There are two alternative ways of interpreting the capping structure, as Ag4S5 mounts, leaving a cubic Ag20 core, or as Ag2S5 mounts, leaving a dodecahedral Ag32 core. Color scheme: gray, carbon, orange, oxygen, blue, exterior silver atoms in

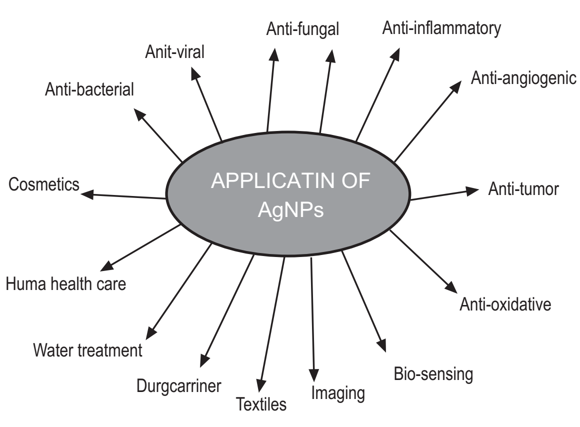

Fig. 1. Various applications of AgNPs.

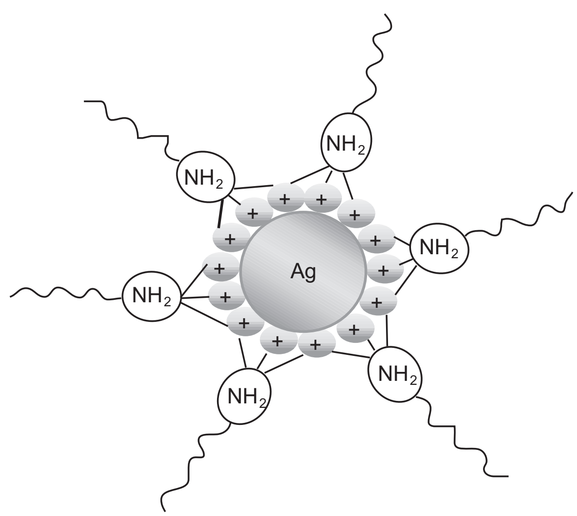

Fig. 2. The suggested structural form of silver nanoparticles (source: Humbatova *et al*., 2016).

the mounts, gold, bridging sulfur atoms in the mounts (Bhattarai *et al*., 2018).

Advantages and disadvantages of using AgNPs. As an antibacterial agent, AgNPs have been used significantly in health industry, in food storage, textile coatings and in several environmental applications. They have also been used as antibacterial agent in medical device and in home appliance fumigation, as well as water treatment cotton fibre. Giving antibacterial effect to the papers used in food packaging will extend the shelf life of the product and food transfer in healthier conditions. The nanoparticles with known antibacterial activity are nanosilver, nanogold, nanosilica. Binders used in paper coating provide a good nutrient medium for bacteria (Kandirmaz and Ozcan, 2019).

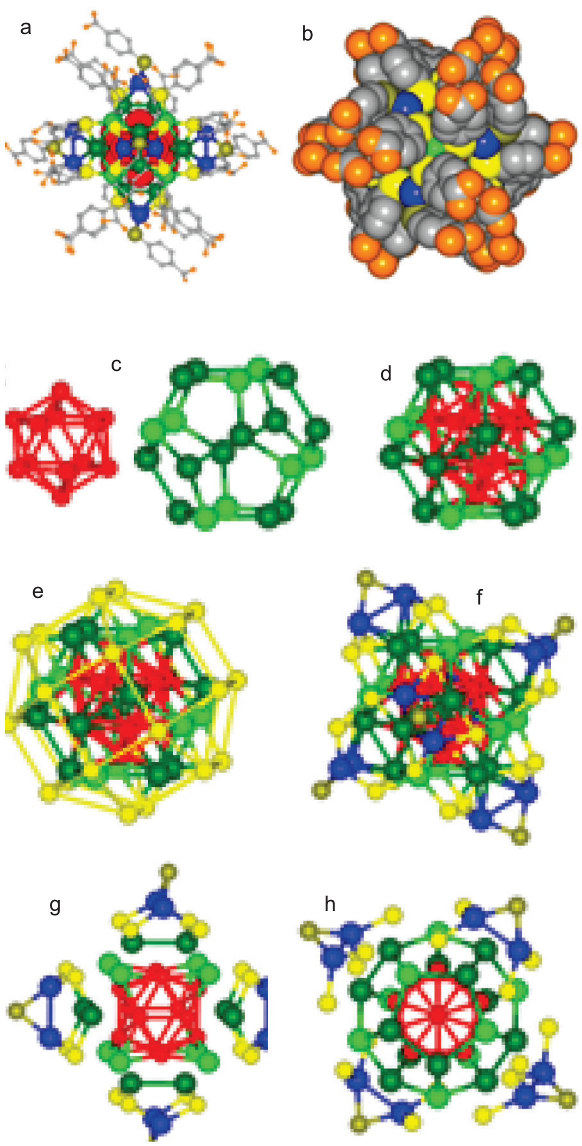

Fig. 3. Structure of a Na4Ag44(p-MBA)30 mNP.

Figure 4, Benefits of AgNPs on food surface packaging Various studies and publications imply that nano silver can have negative health impacts on humans and the environment. Tons of silver are released into environment because of industrial waste, posing a toxicity risk. All living things, including humans, are adversely affected by free silver ions, which might result in persistent bluish-grey discolouration. dosages of 2.25 mg/Kg body weight per day of nanoparticulate silver and 9 mg/Kg body weight per day of ionic silver increased brain concentrations of noradrenaline, dopamine and 5-HT (Hadrup *et al*., 2012). AgNPs are increasingly used in the food industry as anti-caking agents and clarifying agents for fruit juices, as well as in packaging to enable better conservation products such as sensors to track their lifetime. AgNps from food packaging may be unintentionally released into food and end up in the gastrointestinal tract. As a result, human exposure to AgNPs is increasing and it is critical to understand their negative effects. However, there are still disagreements about their toxic effects and mechanisms. To process these nanoparticles and their use, it is essential to understand their harmful impacts on biological systems (Gaillet *et al*., 2015).

Use of silver nano-particles in food packaging and its effect on food. Globally an essential public health

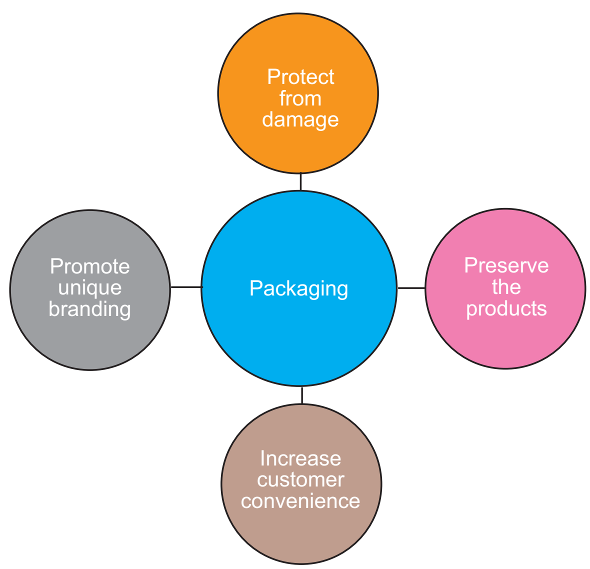

Fig. 4. Benefits of AgNPs on food surface packaging.

issue is hygiene in hospitals, colleges, schools, air, water, animal husbandry, the textile industry and especially the food industry. However, several contemporary interventions have been introduced for reducing contamination but still, it needs attention. Indeed, more than 300 emerging infectious diseases are a significant threat to humans. Microbial infections are a substantial cause of different infections with >50% dieting of various infections in Africa. Various disinfectants have been used to remove bacteria to combat multiple processes. In the broader industries, nanomaterials have provided a new area to solve these problems. The International Organization for Standardization minutes that, even in its mixed domain due to its extraordinary properties, nanomaterials within the range 1 to 100 nm as a substance with specific external dimensions (Rudolph, 2007). The various nanomaterials have been used as efficient disinfectants for optimizing their physico-chemical qualities. Inorganic metals, such as copper, silver and gold, include food supplies, pans, cups, jewelry and coins for the disinfection of water/food and human pollution (Vila and Ampuero, 2007).

Silver-based compounds and silver ions are, in particular, a well known medically necessary antimicrobial agent from 1000 BCE and have been used as an effective health additive in both Indian and Chinese Ayurveda. Silver is preferred because of its different medical roles. Silver nitrate is used as usual for the use of antimicrobials. Still, today nano based silver is antimicrobial due to its physical and chemical properties, which have led to increased microbial surface-to-volume exposure, resulting in better antimicrobial activity (Deshmukh *et al*., 2019).

At present, the use of waste by product processing is taken into account in an environmentally friendly manner. Due to a wide range of applications for many product formulations in the field of personal care, food processing, pharmaceutical and environmental remediation, the development of nano-technological products, in particular, has become more demanding and fashionable (Ampuero and Vila, 2006). The silver nanoparticle (AgNPs) is important because of its fascinating features include reduction power, photochemical activity and electrical conductivity. Antimicrobials and anti-cancer activities have many medicinal applications, including antioxidants (Biswal and Misra, 2020).

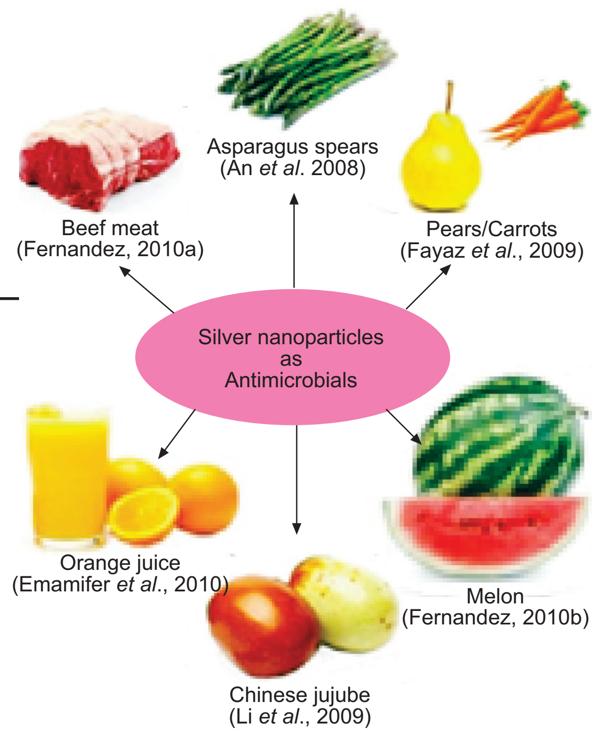

Fig. 5. Silver nanoparticles packaging is antimicrobial, anti-inflammatory and antiviral for different types of food (Source: Rao *et al*., 2017; Emamifer *et al*., 2010; Fernández *et al*., 2010a & b; Fayaz *et al*., 2009; Li *et al*., 2009; An *et al*., 2008).

Table 2. Antibacterial activity of the biologically synthesized AgNPs

Organisms	Zone of inhibition (mm in diameter)				
	AgNPs	$AgNO_3$	Fungal extracts	Positive control	
Pseudomonas aeruginosa	18	10	-	23	2
Staphylococcus aureus	12	9	-	17	3
Escherichia coli	11	8	-	16	4
Shigella sp.	22	10	-	26	5
Bacillus subtilis	10	7	-	14	6
Klebsiella pneumonia	17	8	-	22	

AgNPs = Silver nanoparticles; $AgNO_3$ = Silver nitrate; (-) = No inhibition.

In particular, biopolymers and AgNPs have the potential for active food packaging system development. The diameter of the AgNP is 1-100 nm. Typically, two methods are developed, one is the top-down approach, in which bulk metals are reduced by physical processing like grinding to a nanoscale. The other approach is the bottom-up approach, which can be used in the assembl age of silver atoms biological and processes. Nano-sized silver particles have a large surface-to-volume ratio at high temperatures (Yu *et al*., 2019).

The growing need for better fresh food safety and the need to protect pathogenic foods necessitated the development of antimicrobial food packaging as a matter of urgency. One of the most promising approaches is the combination of organic, inorganic and embedded polymer metal nanoparticles. In particular, the AgNPs are antimicrobial, anti-inflammatory and antiviral and can be combined in active food packaging with non-degradable and comestible polymers (Carbone *et al*., 2016).

Packaging usually includes a range of designs. The first kind called as the primary packaging which consists of the boxes/materials that straight contact the food. A bag of peanuts, tuna canes, jam jars or a covering of a chocolate bar, all known as primary package models, is a box in which a product's device can be accessed on the market (Rundh, 2005). Primary packaging is often primarily restricted in the outer box for storage and transport. For example, a cardboard box with about 20 or 40 tuna cans, secondary packages collected in a regulated 'lot' tertiary package, etc. A central multi-disciplinary area of study, research and development is food packaging itself. For the achievement of good food products (quality and protection etc.) through storage and transport and enhance food safety by avoiding discrepancies with problems and conditions such as chemical pollutants, micro-organism injury, oxygen, humidity and lightening obstacles etc. (Youssef and El-Sayed, 2018).

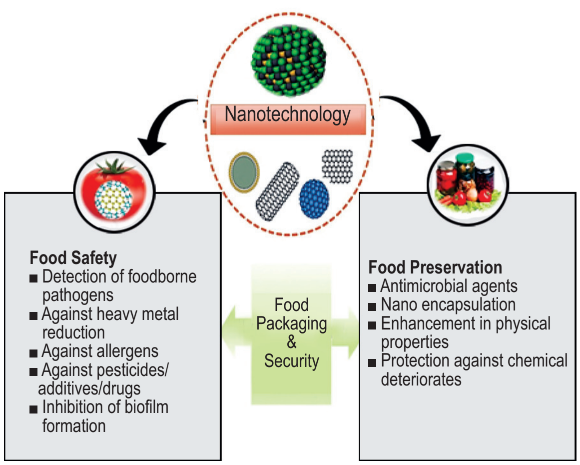

Fig. 6. Relationship of AgNPs food surface packaging with safety and preservation.

Antimicrobials are most often used in metallic nano-particles with various antibacterial activities and profitable abilities such as stability and have relatively low toxicity. Their skillful antimicrobial efficiency is related to the tiny size of particles resulting in the cell penetration of released Ag-ion interactions to amino and carboxyl peptidoglycan cell groups, as well as the generation of oxidative stresses, which affect the replication of DNA or collapse of the proton motive strength over the cytoplasmic membrane (Underwood *et al*., 2001). However, since there is some health and environmental issue with the overuse of AgNPs due to accumulated increase in the amount of released Ag^+ ions and it has been used to develop phytochemicals that have a double role in reducing and capping agents (Suh and Kwon, 2002).

Nanocomposites of polymers containing metal nano-particles or metal oxides have been produced to improve their characteristics (properties of gas barrier, flexibility, antioxidant or antimicrobial properties etc. Silver nanoparticles are used for food packaging due to their antimicrobial effects (Humbatova *et al*., 2016). However, nanoparticles migrating to food are not wholly studied by researchers. The Inductively coupled plasma mass spectrometry (ICP-MS) and Scanning Electron Micro-scopy with Energy Dispersive X-ray (SEM-EDX) research have measured migration solutions and analyzed nanoparticles dissolved in silver that are a key aspect of toxicity (Tiede *et al*., 2008). For all analyzed samples, the total silver migration values ranged from 1.66 to 31.46 ng/cm^2 migration of silver was observed (lower than the permissible limits) (Silayoi and Speece, 2004). The samples were changed in size and morphology (from 10-60 nm) of AgNPs and researchers also tested other nano sized materials that were migrated. Results from all the analyses proved that AgNPs used for food packaging successfully promoted the shelf life of food by protecting it from microorganisms (Echegoyen and Nerín, 2013).

Conclusion

Packaging is an essential and principal element in modernizing trade in goods that preserve food and quality. Food items related to different brands are presented in various packaging colours, shapes, symbols, designs and messages. Worldwide it is an essential public health issue to ensure person hygiene in hospitals, colleges, schools, air, water, animal husbandry, the textile industry and especially the food industry. Nanocomposites of polymers containing metal nanoparticles or metal oxides have been produced to improve their characteristics properties of gas barrier, antioxidant or antimicrobial properties etc. AgNPs are used for food packaging due to their antimicrobial effects.

Acknowledgement

All authors of the manuscript acknowledge and thank their respective University and Department.

Conflict of Interest. The authors declare they have no conflict of interest.

References

Ahmed, A., Ahmed, N., Salman, A. 2005. Critical issues in packaged food business. *British Food Journal*, **107:** 760-780. doi: 10.1108/00070700510623531

Ampuero, O., Vila, N. 2006. Consumer perceptions of product packaging. *Journal of Consumer Marketing*, **23:** 102-114. doi: 10.1108/07363760610655032

An, J., Zhang, M., Wang, S., Tang, J. 2008. Physical, chemical and microbiological changes in stored green asparagus spears as affected by coating of AgNPs-PVP. *Technologie-Food Science and Technology*, **41:** 1100-1107.

Bhattarai, B., Zaker, Y., Atnagulov, A., Yoon, B., Landman, U., Bigioni, T.P. 2018. Chemistry and structure of silver molecular nanoparticles. *Accounts of Chemical Research*, **51:** 3104-3113.

Biswal, A.K., Misra, P.K. 2020. Biosynthesis and characterization of AgNPs for prospective application in food packaging and biomedical fields. *Materials Chemistry and Physics*, **250:** 123014. doi: 10.1016/j.matchemphys.2020.123014

Carbone, M., Donia, D.T., Sabbatella, G., Antiochia, R. 2016. Silver nanoparticles in polymeric matrices for fresh food packaging. *Journal of King Saud University-Science*, **28:** 273-279. doi: 10.1016/j.jksus.2016.05.004

Carlson C., Hussain S.M., Schrand A.M., Braydich-Stolle L.K., Hess K.L., Jones R.L., Schlager, J.J. 2008. Unique cellular interaction of silver nanoparticles: size-dependent generation of reactive oxygen species. *Journal of Physical Chemistry B*, **112:** 13608-13619. doi: 10.1021/jp712087m

Cleveland, C.L., Landman, U., Schaaff, T.G., Shafigullin, M.N., Stephens, P.W., Whetten, R.L. 1997. Structural evolution of smaller gold nanocrystals: the truncated decahedral motif. *Physical Review Letters*, **79:** 1873-1876.

Deshmukh, S.P., Patil, S.M., Mullani, S.B., Delekar, S.D. 2019. Silver nanoparticles as an effective disinfectant: a review. *Materials Science and Engineering*, 954-965. doi: 10.1016/j.msec.2018.12.102

De Moura, M.R., Mattoso, L.H.C., Zucolotto, V. 2012. Development of cellulose-based bactericidal nanocomposites containing AgNPs and their use as active food packaging. *Journal of Food Engineering*, **109:** 520-524. doi: 10.1016/j.jfoodeng.2011.10.030

Emamifar, A., Kadivar, M., Shahedi, M., Soleimanian-Zad, S. 2011. Effect of nanocomposite packaging containing Ag and ZnO on inactivation of Lactobacillus plantarum in orange juice. *Food Control*, **22:** 408-413.

Echegoyen, Y., Nerín, C. 2013. Nanoparticle release from nano-silver antimicrobial food containers. *Food and Chemical Toxicology*, **62:** 16-22. doi: 10.1016/j.fct.2013.08.014

Fernández, A., Picouet, P., Lloret, E. 2010a. Cellulose-silver nanoparticle hybrid materials to control spoilage-related microflora in absorbent pads located in trays of fresh-cut melon. *International Journal of Food Microbiology*, **142:** 222-228.

Fernández, A., Picouet, P., Lloret, E. 2010b. Reduction of the spoilage-related microflora in absorbent pads by silver nanotechnology during modified atmosphere packaging of beef meat. *Journal of Food Protection*, **73:** 2263-2269.

Gaillet, S., Rouanet, J.M. 2015. Silver nanoparticles: their potential toxic effects after oral exposure and underlying mechanisms, a review. *Food and Chemical Toxicology*, **77:** 58-63. doi: 10.1016/j.fct.2014.12.019

Hadrup, N., Loeschner, K., Mortensen, A., Sharma, A.K., Qvortrup, K., Larsen, E.H., Lam, H.R. 2012.

The similar neurotoxic effects of nanoparticulate and ionic silver in vivo and in vitro. *Neurotoxicology*, **33:** 416-23. doi: 10.1016/j.neuro.2012.04.008

Hakkinen, H., Walter, M. 2006. Divide and protect: capping gold nanoclusters with molecular gold-thiolate rings. *The Journal of Physical Chemistry B*, **110:** 9927-9931.

Humbatova, S.F., Zeynalov, N.A., Taghiyev, D.B., Tapdiqov, S.Z., Mammedova, S.M. 2016. Chitosan polymer composite material containing of silver nanoparticle. *Digest Journal of Nanomaterials and Biostructures*, **11:** 39-44.

Imiru, G.A. 2017. The effect of packaging attributes on consumer buying decision behaviour in major commercial cities in Ethiopia. *International Journal of Marketing Studies*, **9:** 43. doi: 10.5539/ijms.v9n6p43

Kandirmaz, A.E. Ozcan, A. 2019. Antibacterial effect of Ag nanoparticles into the paper coatings. *Nordic Pulp and Paper Research Journal*, **34:** 507-515. doi.org/10.1515/npprj-2019-0034

Landman, U., Luedtke, W.D. 2004. Small is different: energetic, structural, thermal and mechanical properties. *Faraday Discuss*, **125:** 1-22.

Li, H.M., Li, F., Wang, L., Sheng, J.C., Xin, Z.H., Zhao, L.Y., Xiao, H.M., Zheng, Y.H., Hu, Q.H. 2009. Effect of nano-packing on preservation quality of Chinese jujube (*Ziziphus jujuba* Mill. var. Inermis (Bunge) Rehd). *Food Chemistry*, **114:** 547-552.

Morris, J.K. 2011. How safe is our food. *Emerging Infectious Diseases*, **17:** 126-128.

Popkin, B.M., Adair, L.S., Ng, S.W. 2012. Global nutrition transition and the pandemic of obesity in developing countries. *Nutrition reviews*, **70:** 3-21. doi.org/10.1111/j.1753-4887.2011.00456.x

Prendergast, G.P., Marr, N.E. 1997. Generic products: who buys them and how are they perceived. *Journal of International Consumer Marketing*, **9:** 55-72. doi: 10.1300/J046v09n04_04

Rao, M., Jha B., Jha A.K., Prasad K. 2017. Fungal Nanotechnology: a pandora to agricultural science and engineering. In: *Fungal Nanotechnology, Fungal Biology*, Prasad, R. (eds.), Springer, Cham. https://doi.org/10.1007/978-3-319-68424-6_1

Rudolph, M.J. 2007. *The Food Product Development Process, Developing New Food Products for a Changing Marketplace*, pp. 75-89, 2nd edition, doi: 10.1201/9781420049084.ch5

Rundh, B. 2005. The multi-faceted dimension of packaging: marketing logistic or marketing tool. *British Food Journal*, **107:** 670-684. doi: 10.1108/00070700510615053

Shiu, E.C., Dawson, J.A., Marshall, D.W. 2004. Segmenting the convenience and health trends in the British food market. *British Food Journal*, **106:** 106-127. doi: 10.1108/00070700410516793

Silayoi, P., Speece, M. 2007. The importance of packaging attributes: a conjoint analysis approach. *European Journal of Marketing*, **41:** 1495-1517. doi: 10.1108/03090560710821279

Silayoi, P., Speece, M. 2004. Packaging and purchase decisions: an exploratory study on the impact of involvement level and time pressure. *British Food Journal*, **106:** 607-628. doi: 10.1108/00070700410553602

Suh, T., Kwon, I.W.G. 2002. Globalization and reluctant buyers. *International Marketing Review*, **19:** 663-680. doi: 10.1108/02651330210451962

Tiede, K., Boxall, A.B., Tear, S.P., Lewis, J., David, H., Hassellöv, M. 2008. Detection and characterization of engineered nanoparticles in food and the environment. *Food additives and contaminants*, **25:** 795-821.

Underwood, R.L., Klein, N.M., Burke, R.R. 2001. Packaging communication: attentional effects of product imagery. *Journal of Product and Brand Management*, **10:** 403-422. doi: 10.1108/10610420110410531

Vila, N., Ampuero, O. 2007. The role of packaging in positioning an orange juice. *Journal of Food Products Marketing*, **13:** 21-48. doi: 10.1300/J038v13n03_02

Wells, L.E., Farley, H., Armstrong, G.A. 2007. The importance of packaging design for own-label food brands. *International Journal of Retail and Distribution Management*, **35:** 677-690. doi: 10.1108/09590550710773237

Whetten, R.L., Khoury, J.T., Alvarez, M.M., Murthy, S., Vezmar, I., Wang, Z.L., Stephens, P.W., Cleveland, C.L., Luedtke, W.D., Landman, U. 1996. Nanocrystal gold molecules. *Advanced Materials*, **8:** 428-433.

Wyrwa, J., Barska, A. 2017. Innovations in the food packaging market: active packaging. *European*

Food Research and Technology, **243:** 1681-1692. doi: 10.1007/s00217-017-2878-2

Yang, H., Wang, Y., Huang, H., Gell, L., Lehtovaara, L., Malola, S., Hakkinen, H., Zheng, N. 2013. All-thiol-stabilized Ag¨ 44 and Au12Ag32 nanoparticles with single-crystal structures. *Nature Communications*, **4:** 2422.

Youssef, A.M., El-Sayed, S.M. 2018. Bio-nanocomposites materials for food packaging applications: concepts and future outlook. *Carbohydrate Polymers*, **193:** 19-27. doi:10.1016/j.carbpol.2018.03.088

Yu, Z., Wang, W., Kong, F., Lin, M., Mustapha, A. 2019. Cellulose nanofibril/silver nanoparticle composite as an active food packaging system and its toxicity to human colon cells. *International Journal of Biological Macromolecules*, **129:** 887-894. doi: 10.1016/j.ijbiomac.2019.02.084