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Nanotechnology Approach in Food Packaging - Review

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Abstract

With changing global trends and consumer preferences, enormous advances has been made by modern food packaging to improve food safety and quality. Nanotechnology being a potent interdisciplinary tool for the growth of new products, this concise review concentrates on implementation of nanotechnology in developing packaging materials for food particularly on food safety. Intelligent and active packaging has proved to be great innovation for the future. Application of nanotechnology will provide new packaging materials enhancing the shelf life of the food material by improving mechanical, barrier and antimicrobial properties. This also outlines the risk that is posed to consumer and environmental safety by some of these novel materials.

Keywords: *- Nanotechnology, Active packaging, intelligent packaging, food safety, shelf life*

1. Food Packaging

Packaging of foods is an art or science or technology required for preparing foods for safe transport or storage or sales elsewhere from the point of production. A packaging provides protection by altering resistance and special physical, chemical or biological needs. Directly connected, and intertwined, with packaging of food, is the theory of shelf life - the span of time that foods, beverages, pharmaceutical drugs, chemicals, and many other perishable substances are given before they are unsuitable for sale, use, or consumption. Elementary packaging materials, such as metal, plastic, glass, paper, paperboard and a mixture of materials of numerous chemical natures and physical structures, are used to satisfy the purposes and necessities of packaged foods depending on their type. However, there has been ever increasing effort in the development of different kinds of packaging materials in order to enhance their effectiveness in keeping the food quality with improved convenience for processing and final use. Few important functions of food packaging are containment, protection, convenience and communication. "Package"- must contain the product except large discrete product. Without containment- product loss & pollution would be widespread, makes a huge contribution to protecting the environment from the products which are moved from one place to another on numerous occasions. It was also discovered, however, that packaging preserves food and prolongs its shelf life by protecting it from bacterial damage, moisture and insect attack, some packaging preserves food for a very long time, such as tins. Today, due to the way we shop, packaging also prevents tampering, provides information and attracts customers. Food packaging is continuously evolving in response to innovations in material science and technologies in addition to ever changing and increasing consumer demands. Packaging also facilitates end use communication and convenience at consumer level. With 2% Gross National Product, Packaging industry is the third biggest firm among the developing countries [13]. Fig 1 shows the market shares of different packaging materials. Designing packages for human environment requires a knowledge of the vision and strength capabilities and limitations of humans, as well as legislative and regulatory requirements. Over the period, the growth of novel food packaging (active packaging & modified atmosphere) brought convenience to consumers by increasing the shelf life as well as the safety and quality of foods. Possessing enhanced function intelligent packaging systems gives importance to marketing functions and communication by delivering dynamic feedback to the consumer on the true quality of the product. However, active packaging concentrates on providing food protection and preservation by certain mechanisms activated through intrinsic and/or extrinsic factors [22].

2. Drawbacks Of Existing Packaging Materials

Lack of recyclability, non-sustainable production, inadequate mechanical and barrier properties are certain challenges tackled by the packaging industries (Table 1). Despite the fact that metals and glasses are fine barriers to evade undesirable transport in packaging, plastics are still prevalent because of their cost effectiveness, formability, light weight and flexible characteristics. Therefore, packaging industries consumes almost 40% plastic with most of it used for food packaging [29]. Nevertheless, the majorities of packaging materials are non-biodegradable and petroleum based. The critical issue in food packaging is weak barrier properties to gases and water vapor. Although the functional properties of thermoplastic (matches barrier performance for some products) has been expanded by developing polymer blends and multilayered structures, complications remain unanswered such as the difficulty in recycling of these materials and high cost. The important problem for the packaging industry is to broaden the shelf life of the food products to be packed. Contamination by microorganism, influence of extrinsic factors (such as light), change in temperature etc. compromise with the shelf life of the product. All these limitations trigger the researchers to introduce nanotechnology in the field of packaging and expand new superior packing materials which are cheap effective efficient and safe. Though packaging can do a lot to attract customers, it also adds to the eventual retail price and the cost of the product. Packaging accounts for almost 40% of the total cost of the final product. Significant amount of waste stream is from the packaging department in a food industry. Waste can be recycled but not all wastes are recyclable.

3. Nanotechnology In Food Packaging

In the dominion of packaging, nanotechnology is been adopted much more rapidly. Whereas there are still worries about the degree to which nanomaterials can leak into food from the packaging, and the consequence they may have on consumers health, most exploration so far looks encouraging, and the aids are highly perceptible - numerous nano-enhancements for packaging are at present in the market, helping to extend the shelf life of food and making it easier to manage, process, and manufacture. No pure polymer is known to exhibit all the desired barrier and mechanical properties required for every conceivable packaging of food. Sustainability of the nano packaging must also be deliberated. Although multilayered thin films may function exceptionally, it will be very tough to reuse or recycle, and may use limited raw materials and manufacturing processes that are energy-intensive and produce momentous amounts of waste. The substantial drive of nano packaging is to increase the shelf life. This is done to decrease the gas and moisture exchange and UV light exposure by enhancing the barrier functions of packaging [33]. To extend the shelf life, nano packaging can also be designed to discharge antioxidants, enzymes, flavors, antimicrobials or nutraceuticals [21]. Nanomaterial integrated packaging can be "smart" means that it can react to environmental circumstances, repair itself or give contamination alert to consumer and pathogen presence [5].

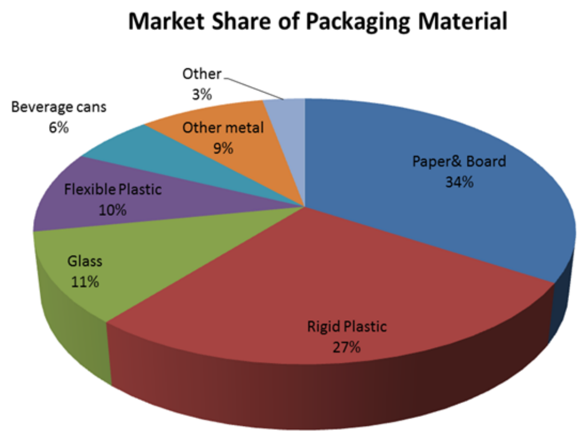

Fig 1- Figure showing different packaging materials and their market share
(Picture courtesy: - Jane Muncke 2012, Food packaging forum)

3.1 Polymer Nano composites

The amazing potential of polymer nanotechnology has pulled the attention of researchers, from chemistry, physics and biology to engineering and have offered assisting ways for the growth of high-performance materials. Flourishing development of polymer nanomaterial for packaging of food (PNFP) has to overcome the hurdles in safety, standardization, regulation, technology and trained workforce to benefit the commercial products from the global market potential and therefore needs a high degree of multidisciplinary [7].

Polymer nano composites are single or a mixture of polymers with at least one inorganic or organic filler, which has dimensions less than 100 nm which can be prepared using nanoparticles – Fig 2. It is studied that incorporation of nanoparticles like SiO_2 [36], clay [17, 38], TiO2 [18], $KMnO_4$ [19], nanocellulose [1], SiC [8], Nano fibrillated cellulose (NFC) [25], carbon nanotubes [40], and etc., into synthetic polymers and biopolymers can increase their mechanical and barrier properties. Polymer nano composites are stronger, possess better thermal properties and are more flame resistant than commercial polymers.

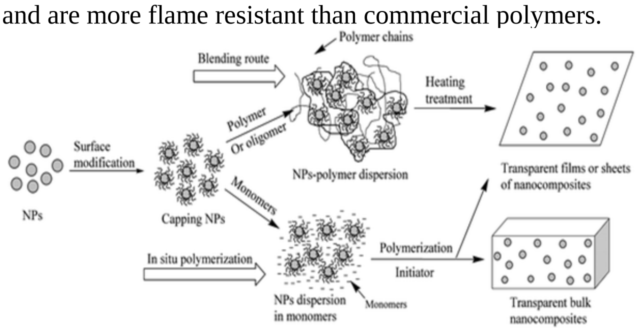

Fig 2- Preparation of Polymer nano composites using nanoparticles
(Picture Courtesy: - Jixin Yang et al., 2008, Journal of material Chemistry)

Commonly used barrier materials, are aluminum coatings on plastic films that are vacuum-deposited, for packaging coffee, confectionery and snack foods. The 50 nm thick aluminum coating qualifies as a nanomaterial, being on the one dimensional nano scale. Likewise, treating surfaces of glass beverage containers with organosilanes, with plasma or high temperature technology, are quite common. Rate of adsorption for gas molecules into the matrix at the atmosphere/polymer boundary and the rate of diffusion for adsorbed gas molecules through the matrix decide the permeability of polymeric materials for gases [28]. Recently, incorporating nano platelet clays into polymers has been used to reduce the diffusion rate by impeding the passage of tainting and aroma compounds, oxygen and water (Fig 3). Frequently, incorporating less mass fraction, for example a small percentage in the nano composites, will enhance barrier properties compared to the polymer alone [11].

Further, the nano fillers impact the barrier properties by triggering the polymer matrix in the interfacial regions. If the interactions of polymer–nanoparticle are encouraging, polymer strands will be partially immobilized that is situated close to each nanoparticle. The outcome being, the gas molecules passing through the interfacial zones has weakened their rate of hopping between free volume holes, or altered density and or size of holes, a circumstance which has been viewed directly with the use of positron annihilation lifetime spectroscopy (PALS) [26, 31].

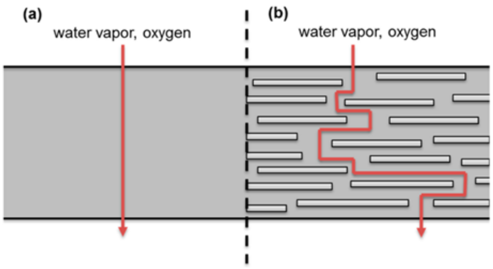

Fig 3- Illustration of incorporation of nano platelets leading to the tortuous pathway

(Pic Courtesy: - Timothy V. Duncan, 2011, Journal of colloid and Interface Science)

(a), diffusing gas molecules take a pathway that is perpendicular to the film orientation. But in a nano composite (b), diffusing molecules steer around impermeable platelets and through interfacial zones which have different permeability characteristics than those of the polymer. This pathway increases the shelf-life of spoilable foods by increasing the mean length of gas diffusion.

3.2 Biodegradable Nano composites

The bizarre triumph of the nanocomposite concept in synthetic polymers has encouraged an innovative research on nanocomposites, based on biodegradable polymers as matrix. Faster rate of degradation can be obtained from nano filler scattered in a bio compatible polymer. Bio composites based on nano clay have fascinated significant interest due to their enhanced mechanical and barrier properties, in addition to their biodegradability owing to environmental benefit [3]. The final step in the process of degradation of biodegradable plastic polymers must be in the presence of naturally occurring organisms through metabolism. Biodegradation leads to plastic disintegration or fragmentation without toxic or environmentally detrimental residue, provided with suitable conditions of moisture, oxygen availability and temperature [6]. Major biodegradable nanocomposites that suits packaging applications are starch and its derivatives, Poly (Butylene Succinate) (PBS), Poly Lactic Acid (PLA), Poly Hydroxy Butyrate (PHB). Bio-derived polysaccharide (starch) (Fig 4) based polymers, due to their biodegradability, have reaped attention and likely to have an even larger reliance of the oxygen transfer rate on humidity level. This has narrowed their usefulness. Cost, performance and processing are the problems related with biodegradable polymers. High vapor and gas and permeability, low heat distortion temperature, deprived resistance to extended processing operations have intensely restricted their applications [34].

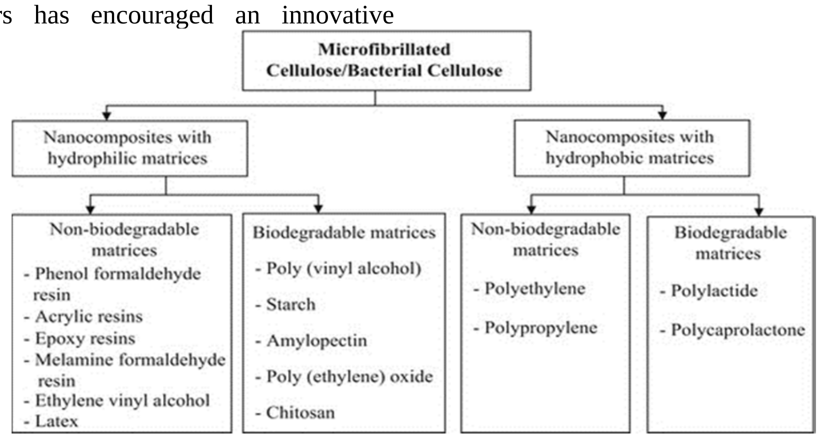

Fig 4- Classification of nano composites

(Picture Courtesy: - Sarang Bari et al., 2016, Handbook of Polymer nanocomposites.)

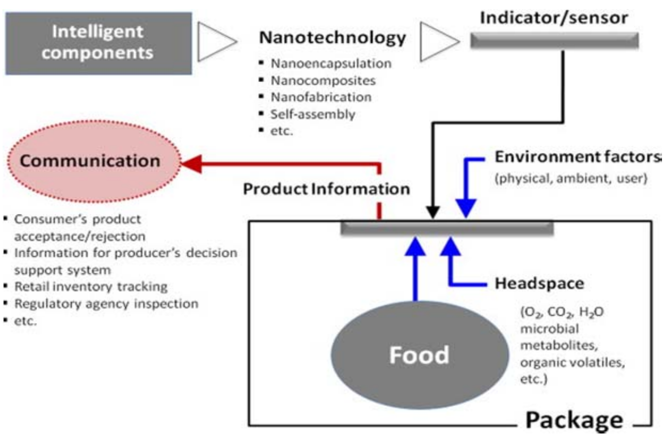

Fig 5- Intelligent packaging

(Picture Courtesy- S.D.F. Mihindukulasuriya et al., 2014, Trends in Food Science and technology)

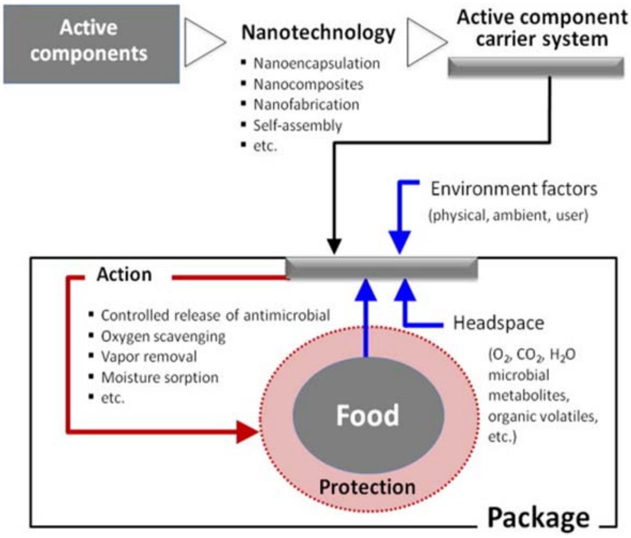

Fig 6- Active Packaging

(Picture Courtesy- S.D.F. Mihindukulasuriya et al., 2014, Trends in Food Science and technology)

3.3 Nanotechnology in Intelligent Packaging

Intelligent packaging incorporates sensors and sometimes nanosensors. It is the new generation of packaging and many are in the late developmental stages. They can alter the conditions of the package to delay spoilage and also communicate information concerning the food to the consumer or respond to the information [27]. The trademark of intelligent packaging systems is to increase the communication feature of a package, for instance to vigorously replicate the original food quality in real time, contrasting to the fixed “Use By” and “Best Before” dating approach. Nanoparticles are used as reactive particle in packaging to notify the condition of package (Fig 5). The so called nanosensors have the ability to react with microbial contamination, changes in environment (such as humidity or temperature in storage rooms, oxygen exposure level) or degradation products [2]. The sensor is made-up using appropriate nanotechnology. It can interrelate with external environmental factors and internal factors (food components). Consequently, response will be generated by the sensor (e.g., electrical signal, visual cue) that correlates with the condition of the food product. Recent developments in fixing oxygen indicators with the packaging as presence of oxygen allow the growth of aerobic microorganism during storage of food. The quality of food is also communicated to the customers by placing freshness indicators. Indicators of freshness for packaging of food are a vital prerequisite in the positive improvement of freshness indicators. It is the understanding about the quality-indicating metabolites. A freshness sensor should respond to the occurrence of these metabolites with the essential sensitivity [32]. “Electronic Tongue” technology, an additional growth in the field, is made using sensor arrays to indicate the state of the food. This device includes an array of sensors tremendously sensitive to gases, which are released by microorganisms causing spoilage, producing color changes that indicate whether the food is deteriorated [24].

3.4 Nanotechnology in Active Packaging

Active packaging ideas exist where the packaging is envisioned to change the composition or nature of the food or the atmosphere that backgrounds the food in the pack (Fig 6). Since nanoparticles are present at very high surface area, they hold a large probability for trapping or releasing chemicals. For instance, when additives such as colors or preservatives are needed, nano encapsulates can be used to discharge the additives onto the food surface. The combination of active substances and food packaging materials is a new approach to restrict surface microbial food contamination. Certain nanomaterials, like silver, gold and zinc, show antimicrobial effects. Silver nanoparticles have numerous commercial applications. Due to the property of low volatility and high temperature stability, silver at the nanoscale is identified to be a good anti-microbial and anti-fungal agent. It is claimed to be effective against more than 100 different bacteria [20]. Silver has several advantages compared to other antimicrobial agents. Silver is toxic and has broad spectrum to various strains of fungi, bacteria, algae, and certain viruses. On the other hand, other molecular antimicrobials are normally specific to organisms (to varying degrees). Silver is shelf stable for long time. It is also reasonably effective at biofilm penetration, which is not achieved by many molecular antimicrobials [9]. Nano silver particles can disrupt their barrier components, like lipopolysaccharides and proteins, and pierce into membranes (outer and inner) of the cells, Silver nanoparticles have the capability to hinder enzymes in respiratory chain and obstruct the penetration of phosphate and protons across the membrane, thus reducing the level of ATP [12]. This attributes to the antimicrobial activity of silver nanoparticles. The high catalytic movement of nanoparticles can result in toxicity and oxidative stress within the microbial cells due to the formation of reactive oxygen species [23]. Conventional viewpoint is that silver atoms cause cellular destruction in the same manner (observed for conventional silver antimicrobials) by detaching from the silver nano particles surface. Silver nano particles are efficient media to convey a huge quantity of silver ions to the cell interior in a short period of time [35]. Carbon nanotubes can be exploited for their antibacterial properties apart from improving the polymer matrix properties. Straight contact with CNT masses was found to be fatal for E.Coli, because long and thin CNTs puncture the microbial cells causing irreversible damages [16]. The application of carbon nanotubes are stopped at present since quite a few studies reported that when in contact to skin, CNTs are cytotoxic to human cells [37]. Compared to nanosilver, ZnO and MgO nanoparticles is likely to present more safe and reasonable packaging of food in the future. ZnO displays increasing antibacterial activity with decreasing particle size [39]. This activity can be stimulated even with visible light and does not necessitate the presence of UV light [15].

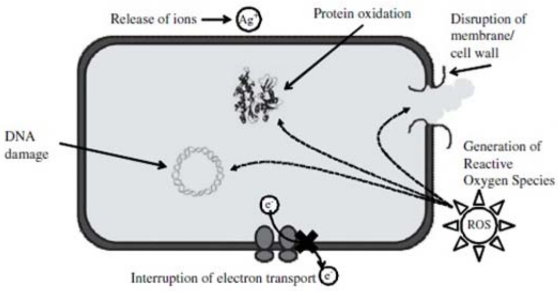

Fig 7- Incorporation of Nanoparticles resulting in generation of ROS

(Picture Courtesy: - Nanotechnology and Nanomaterials » "Advances in Nanocomposite Technology")

	Product characteristics/food compatibility		Consumer/marketing issues		Environmental issues		
Material	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Advantages**	**Disadvantages**	**Cost**
Glass	• Impermeable to moisture and gases • Nonreactive (inert) • Withstands heat processing	• Brittle and breakable • Needs a separate closure	• Transparent, allows consumer to see product • Can be colored for light-sensitive products	• Poor portability: heavy and breakable • Relatively difficult to decorate	• Reusable • Recyclable • Often contains recycled content	• Heavy and bulky to transport	• Low cost material but somewhat costly to transport
Aluminum	• Impermeable to moisture and gases • Resistant to corrosion • Withstands heat processing	• Cannot be welded • Limited structural strength	• Easy to decorate • Lightweight • Good portability, lightweight, and not breakable	• Limited shapes	• Recyclable • Lightweight • Economic incentive to recycle	• No disadvantages in rigid form • Separation difficulties in laminated form	• Relatively expensive but value encourages recycling
Tinplate	• Impermeable • Strong and formable • Resistant to corrosion • Withstands heat processing	• Can react with foods; coating required	• Easy to decorate	• Typically requires a can opener to access product	• Recyclable • Magnetic thus easily separated	• Heavier than aluminum	• Cheaper than aluminum
Tin-free steel	• Strong • Good resistance to corrosion • Withstands heat processing	• Difficult to weld, requires removal of coating • Less resistant to corrosion	• Easy to decorate	• Typically requires a can opener to access product	• Recyclable • Magnetic thus easily separated	• Heavier than aluminum	• Cheaper than tinplate
Polyolefins	• Good moisture barrier • Strong • Resistant to chemicals	• Poor gas barrier	• Lightweight	• Slight haze or translucency	• Recyclable[a] • High energy source for incineration	• Easily recycled in semi-rigid form but identification and separation more difficult for films	• Low cost
Polyesters	• Strong • Withstands hot filling • Good barrier properties		• High clarity • Shatter resistant		• Recyclable[a,b]	• Easily recycled in rigid form but identification and separation more difficult for films	• Inexpensive but higher cost among plastics
Polyvinyl chloride	• Moldable • Resistant to chemicals		• High clarity		• Recyclable[a]	• Contains chlorine • Requires separating from other waste	• Inexpensive
Polyvinylidene chloride	• High barrier to moisture and gases • Heat sealable • Withstands hot filling		• Maintains product quality		• Recyclable[a]	• Contains chlorine • Requires separating from other waste	• Inexpensive but higher cost among plastics
Polystyrene	• Available in rigid, film, and foam form	• Poor barrier properties	• Good clarity		• Recyclable[a]	• Requires separating from other waste	• Inexpensive
Polyamide	• Strong • Good barrier properties				• Recyclable[a]	• Requires separating from other waste	• Inexpensive but higher cost among plastics
Ethylene vinyl alcohol	• High barrier to gases and oils/fat	• Low moisture barrier/ moisture sensitive	• Maintains product quality for oxygen-sensitive products		• Recyclable[a]	• Requires separating from other waste	• Inexpensive when used as thin film
PLA	• Biodegradable hydrolysable				• Recyclable[a,c]	• Requires separating from other waste	• Relatively expensive
Paper & paperboard	• Very good strength to weight characteristics	• Poor barrier to light • Recycled content makes it unsuitable for food contact material	• Low-density materials • Easily decorated • Efficient, low cost protection	• Moisture sensitive, loses strength with increasing humidity • Tears easily	• Made from renewable resources • Recyclable[b]		• Low cost
Laminates/co-extrusions	• Properties can be tailored for product needs		• Flexibility in design and characteristics		• Often allows for source reduction	• Layer separation is required	• Relatively expensive but cost effective for purpose

[a] All thermoplastics are technically recyclable and are recycled at the production environment, which contributes to lower cost. As inexpensive materials, postconsumer recycling competes with ease of separating and cleaning the materials.
[b] Recycled extensively for nonfood product uses.
[c] Can be broken down to monomer level and reprocessed.

Table 1- Environmental issues, Properties and Cost of packaging materials

(Picture Courtesy-IFT)

4. Safety Aspects Of Incorporating Nanotechnology In Food Packaging

Consumers are very doubtful in consenting new technologies in their foods and nanotechnology is not an exemption. Nanotechnology plays a key role in filling the cracks of packaging material improvements in active as well as intelligent packaging areas. Although, the major danger concerned with nano components in the food industry is the possibility of severe health effects [10]. Nature nanotechnology includes an editorial article that proclaimed ‘‘up to 400 companies around the world are researching possible applications of nanotechnology in food and food packaging – and many of them do not want their customers to know this’’[4]. Three diverse ways of nanoparticle penetration in an organism are: inhalation, ingestion and entrance through skin penetration. Two studies examined movement of clay from films of potato-starch and potato starch polyester blends and PET bottles. Both the cases showed inconsequential noticeable migration of nanoclay. The properties of nanomaterial is the important characteristic that determines the effect nanomaterial on human body. When the nanoparticles are positively charged and hydrophilic in nature it tends to increase the circulation time. These nano particles have severe effect on microcirculation. A new study reports the movement of silver nanoparticles from higher than the level of silver migration is detected [7]. The most concerned organ is the brain. It is observed to have increased production of reactive oxygen species in microglial cells [42]. Food packaging nanomaterials, the inhalation and the appearance through skin penetration is almost completely related to workers in the factories. Occurrences of nanoparticles in food are mostly consequence of straight contact of nano packaging and food and immigration of nanoparticles from nano packaging materials [42]. Accepting food products by the public that employ or integrate nanomaterials will be based fundamentally on how much trust they have on the packaging industry. Apart from toxicity, genotoxicity and carcinogenicity (Fig 7) are one of the likely adversative effects of nanoparticles which draws the most attention. ZnO nanoparticles have a genotoxic potential in human epidermal cells even if bulk ZnO is non-toxic, which suggests the impact of particles' diameter [42]. Carcinogenic effects of persistent particles such as asbestos have been suggested to be due to the local generation of granulomas and fibrosis in the lungs [41].Nanoparticles may form compounds with other food materials or interact with each other, or stay in a free state when it is present in the alimentary canal. However, the effects of this on the absorption still remains unknown. The enlarged use of such nanoforms may call for the revision of the Recommended Daily Allowances (RDA) of the food ingredient. Different countries follow different rules and regulations for the use of nanotechnology to ensure safety of their fellow countrymen. Safety and health properties of most nanomaterial is unspoken and safety is the major concern when relying on nanomaterials for packaging applications. Thus, detailed toxicological analysis is required to elucidate the risks concerned before it is being used by packaging industry.

5. Conclusion

Application of nanotechnology in the food system, the possibilities of improving food quality, stability, safety and efficacy as novel packaging are just touching pores of our fingers and in the near future it might be under our grip. Though nanomaterials have some exhilarating aids in the food industry including the packaging of foods and determining the safety of food, nanotechnology is very fresh and future of it in food industry remains uncertain. Nanotechnology based packaging increases the communication and relation between both producers and consumers, but the safety aspects of it is still under consideration. Preventive measures should be functional and more research is required to focus on the movement of nanomaterials from the packaging material to the food. Apart from the safety factor there arises a lot of ethical issues for use of this technology which is yet to be answered. The way in which the issue of nanotechnology in packaging of food is handled by industries, government and NGO's will influence the public's reaction. Therefore, the nanomaterials require regulation before they are incorporated into food contact and packaging.

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