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Applications of Nanotechnology in Food Packaging

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Abstract—*The minute nanocreations (amino acids, DNA, hormones, sugars) of life-supporting mother nature serve as an evidence that nanoscience has been in existence since mother nature came into being. Then what is so recent about this technology? The answer lies in its fresh innovative applications in various sectors. One such sector where the benefits of this technology can and are immensely being reaped is the food packaging sector. Let us see in what numerous ways it is benefitting this zone of food science and technology. The poor mechanical strength of biopolymers can be improved by incorporating nanoparticles, which can then be used as an effective environment- friendly packaging material. Moreover, antimicrobial property can also be imparted to the packaging material by reinforcing metal nanoparticles (with antimicrobial characteristics) into the polymer matrix. Nanodevices such as nanosensors can be used to report any spoilage or adulteration in packaged food. Without going into any fastidious scrutiny, we all can relate to the fact that one of the most prevailing causes of food spoilage is oxidation. Here, nanotechnology can again come to the rescue by paving the way for the development of such nanocomposites which exhibit good oxygen barrier properties. Nanoscience can also be employed for product (food package) tracking through the use of nanobarcodes to ensure that food packet travels through the right supply chain and ultimately reaches into the right hands.*

1. INTRODUCTION

According to National Nanotechnology Initiative," Nanotechnology is science, engineering and technology conducted at the nanoscale, which is about 1 to 100 nanometers." [1]

Although the conceptualisation of this technology began when in 1959, Richard Feynman delivered a speech titled "There's Plenty of Room at the Bottom" at California Institute of Technology (CalTech) [1,2], the existence of this technology has been there since mother nature came into being [3]. Life-supporting fundamental biomolecules such as sugar, amino acids, DNA, hormones, most of the proteins and polysaccharide molecules: all range in nanosize and serve as an evidence to this fact [3]. Indeed, scientists have been doing research and making discoveries based on this inter-disciplinary science for more than a hundred years. For instance, Louis Pasteur's work with spoilage bacteria (1866), Watson and Crick's discovery of structure of DNA (1953) can be envisaged as nanoscience[4]. The only difference is that now we have categorised it into an entirely different field of study named "Nanotechnology" [4].

After making its mark in fields of medical treatment and diagnostics, energy production, molecular calculations and structural materials, Nanotechnology has paved its way into the food sector as well and the most energetic division of food nanoscience research and development is packaging: the worldwide nano-faciliated food and beverage packaging market was 4.13 billion US dollars in 2008 and had been planned to grow to 7.3 billion by 2014. According to some research studies, it is mainly because people are more ready to accept nanotechnology in "outside food" applications than those where nanomaterials are straightaway incorporated into the food [5].

As most of the work in food nanoscience is being focused in the packaging sector, the whole aim of this article is to update the readers the numerous ways in which nanotechnology is being applied in the food packaging sector. Food packaging materials being used nowadays have many shortcomings like non-biodegradable nature, poor barrier properties etc. which needs to be overcome if the food processing sector is to be strengthened as a whole because packaging forms an integral role of it. Features of an ideal packaging material, namely,strong yet light-weight, good barrier properties, cost effective, achieving shelf life extension while maintaining the optimal quality and safety of food product, providing extra nutrients, impressive appearance, suitable for all weather conditions can be achieved using nanotechnology.

1.1 Environment friendly solutions

Eco-friendly materials like biopolymers can prove to be an efficient packaging material provided its weak barrier properties could be rectified [6]. So, in order to overcome the defect of weak barrier properties, different fillers were used to strengthen the biopolymers but these fillers showed poor matrix-filler interactions. As the scale of fillers was reduced to nanosize, good matrix-filler interactions were achieved and the barrier properties of materials were improved [7].

In this context, Polylactic acid (PLA) serves as a good example. PLA, due to its good properties such as high biodegradability and UV stability, has gained attention as a packaging material. Still, there are some limitations like poor barrier properties which confine their uses as a packaging material. This problem can be bridled by bracing nanofillers like nanoparticles, nanoplatelets, nanotubes etc. into the PLA matrix **[**7]**.**

Recently, Johnsyet. al. (2014) prepared Hybrid Hydroxypropyl methyl cellulose (HPMC) based nanomaterial fortified with bacterial cellulose nanocrystals (BCNC) and silver nanoparticles (AgNPs) with superior properties such as decreased hydrophilicity and improved barrier properties and it is expected to be useful in eco-friendly packaging applications [8]**.**

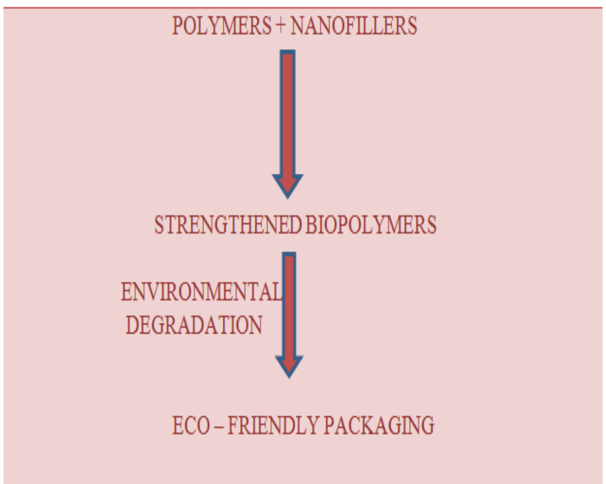

Fig. 1: Process flow diagram highlighting the environment-friendly degradation of the nanopackaging

1.2. Improved antimicrobial functionality of packaging material

Nanoparticles of metals like silver, gold, zinc oxide, titanium dioxide etc. are being incorporated into the packaging material to equip them with antimicrobial property. As a result, this nanoparticle embedded packaging arrests the multiplication of spoilage causing microorganisms and thus extends the shelf life of food. Moreover, the metal nanoparticles have proved to be much more effective than the metal microparticles. Dammet. al. (2008) showed that polyamide-6 film having 1.9 wt. % silver microparticles eliminated 80% of the bacteria whereas polyamide-6 film having 0.06 wt. % of silver nanoparticles removed the bacteria completely **[**6]**.**

Each nanoparticle showcases certain special germicidal attributes which can be put to use as and when desired in the food packaging sector. For instance, silver nanoparticles in their ionic form can hinder vast extent of biological processes in bacteria [10]**.** Pure silver colloid, brought down to 1 nm size with atomic particles, is profoundly aseptic, adept of accomplishing 99.9 % kill against 650 species of microorganisms within 6 minutes when in fact regular antibiotic is competent only against 5-6 species **[**11]**.** The antibacterial property of zinc oxide nanoparticles increases as the particle size decreases and they can be triggered by visible light. Titanium oxide is used in amalgamation with silver to boost the disinfection process **[**10]**.**

Nanoparticles are not only being added to the packaging films, they are also being used as coatings on food containers to prevent deterioration of food kept inside it **[**11]**.**

1.3. To detect food spoilage during storage, handling and distribution

If food is unpacked, any kind of spoilage is very easily affirmable because sensory parameters like colour, smell, taste etc. can be immediately used by consumer to make sure whether the food is fit for consumption or not. But when food is enwrapped in a packaging material, sensory exposure from the food is cut and consumers need to depend on less reliable information such as expiry dates given by producers based on the set of certain presumptions about the manner in which the food is stored or transported. Anyhow, if the storage, handling or distribution conditions in a specific time frame are not maintained as required and the actual standard of food has decreased, it might not be recognised by consumer unless the package is removed. So, in order to detect food spoilage in packaged food, nanosensors are being used which can help the consumer in purchasing fresh food product **[**12]**.**

Different nanosensors such as electronic tongue, electronic nose, microfluidic devices, nanoelectromechanical systems (NEMS), micro- and nano- technologies (MNTs), nanocantilevers are used to lessen the time for spoilage detection from days to hours or even minutes [9].

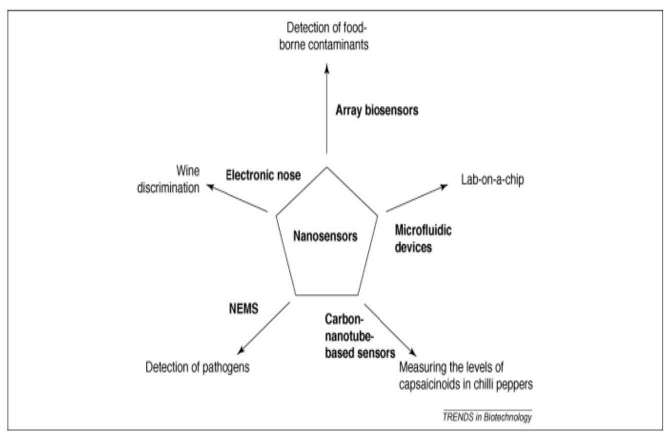

Fig. 2: Types of nanosensors and the examples of their applications in food sector (Adapted from Sozer et. al., 2008)

Each type of nanosensor uses different principle to detect food spoilage. For instance, Electronic tongue has been formed by Kraft Foods which works on the principle of colour change. It is integrated straightaway into the packaging material and is responsive towards gases released during spoilage. These gases, in turn, cause colour change of the nanosensor strip which signals the consumer that the quality of the food has deteriorated [13].

Nanosensors can also be used to detect adulteration that must have taken place during different unit operations of producing packaged food. Naveen et. al. (2014) used citrate-stabilised gold nanoparticles for developing colorimetric detection method to check melamine adulteration in milk [14]. It proved to be a much faster and cost-effective detection method as compared to chromatography and immunoassay-based analytical methods. Likewise, such detection methods based on nanotechnology can also be developed for many more food products.

1.4. Prevention of oxidation

Once packaged food comes into the contact of oxygen, it starts degenerating and unwanted changes occur in the food. So, in order to eschew this food quality decline, oxygen has to be completely wiped out from the package or it has to be brought down to a satisfactory level [6].

To deal with this problem, nanoparticles are being used to develop nanocomposites which possess oxygen barrier properties [6]. For example, Durethan is a nanocomposite film from Bayer Polymers (Pittsburg, USA) which contains silicate nanoparticles that lowers the penetration of oxygen into the packaging material [15].

Furthermore, oxygen indicators are also being designed with the help of nanoparticles. For instance, a UV activated form of oxygen indicator is made with the help of TiO_2 nanoparticles [6]. Similarly, Mihindukulasuriyaet. al. (2013) made a UV activated oxygen indicator membrane using TiO_2 nanoparticles and the reactivity of this membrane was more than that of the cast membrane carrier [16]. These oxygen indicators make sure that the oxygen concentration does not increase beyond an acceptable limit in the packaging material.

1.5. Product tracking

Nanobarcodes called Radio Frequency Identification (RFID) tags have been developed which allow to track food packets throughout the product supply chain [13]. RFID machinery, which comprises of microprocessors and an antenna that transfers data into a wireless receiver, is used to trace the food item from storehouse to customer's hands [17]. Thus, if any kind of adulteration has occurred in the packaged food or if the product, destined for a particular market, has been deflected to different market, it can be easily known through RFID technology [18].

Also, invisible nanobarcodes which can be inscribed directly on food package, can be used for ensuring greater product safety because these will help brand holders to monitor their supply chain without having to disclose company information to other traders [18].

Edible nano-enabled tracking systems are also being developed. pSiNutria, a Nanotech Company is instigating nano-enabled tracking technologies which can be positioned in food for tracking purposes and it can also be consumed.

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