India Food Safety Conclave 2025

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Are Innovations in Food Packaging Technology Sustainable?

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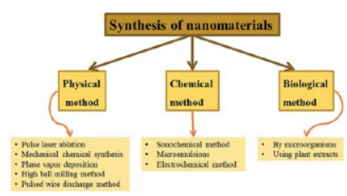
Introduction

Food Packaging is essential to understand food safety and quality. The determination of food contamination and intoxication can be attributed by external factors like moisture content, relative humidity, temperature, dust as well as damaged packaging. Food packaging traditionally used petroleum based plastics, glass, canning materials, metals and cheap paper to process packaging and make it accessible.Plastics like polyethylene and polypropylene have been labelled non biodegradable and purposefully contributes to pollution, microplastic intoxication, and infection. Synthetic chemicals like Bisphenol A(present in Epoxy Resin) and phthalates from plastics disrupt the endocrine system and act mycoestrogenic. Metal packaging like aluminum, tin leeches harmful byproducts into food, possibly causing digestive issues and worsening neurodegenerative conditions. In case of dairy packaging, use of biodegradables like seaweed-based films and corn plastic are ideal for milk sachets, yogurt containers, and cheese wraps. This helps in offering moisture resistance while reducing plastic use. For processed meats, chromatogeny-coated cellulose and recycled fishing net plastics are used. It leads to effective oxygen and moisture barriers. Sometimes Nitrogen flushing is also used to replace oxygen in the meat packaging. Packaging made from cow manure can be used as a renewable alternative for meat or meat analogues. Fresh fruits and vegetables use plantable seed paper along with grass cardboard, which are compostable and increase ecological value. There are 3D-printing and biodegradable packaging to protect material waste. In the bakery industry, FibreForm paper tubes and oyster paper increase shelf life for cookies, pastries, and bakery items. The molded fiber packaging allows for recyclable, custom-printed trays. These reduces carbon footprint and increases shelf life.



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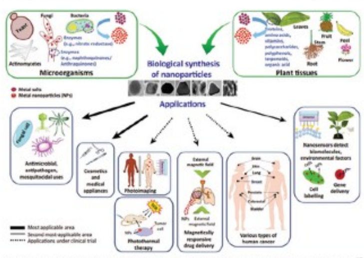

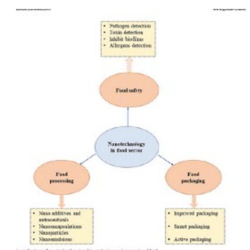

Methodology

Use of Bio Polymers in Food Packaging

Cellulose

Cellulose is a naturally occurring, biodegradable biopolymer that is frequently utilised in food packaging due to its superior oxygen barrier qualities. It has strong hydrogen bonding, which limits oxygen permeability, packaged foods have a longer shelf life. However, when exposed to humidity, its hydrophilic nature reduces its ability to withstand moisture, which might result in structural problems. Researchers have improved cellulose films with waterproof coatings or additions like fatty acids and nanoclays to get around this. Cellulose is a crucial component in the transition to environmentally friendly packaging solutions because of advancements like cellulose-based quality indicators and nanocomposite films, which show off its potential in intelligent packaging by providing environmental sustainability recyclability, and even visual spoilage detection.

Chitosan

Derived from the chitin found in crab shells, chitosan is a sustainable biopolymer that is valued for its inherent antibacterial qualities, capacity to form films, and biodegradability. It is perfect for food packaging since it creates flexible, translucent films with superior gas barrier properties. Aromatic oils or nanoparticles can be added to chitosan-based films to increase their antibacterial and antioxidant properties. For instance, chitosan-nisin films containing perilla oil kept fish that were ready to eat for 12 days, and chitosan infused with silver nanoparticles increased the shelf life of strawberries and prevented the formation of bacteria. Chitosan is a great contender for creative, sustainable packaging for food solutions because of its environmentally benign origin, usefulness, and regulatory compliance.

Polylactic Acid

A popular biopolymer made from sustainable sources like corn and sugarcane, polylactic acid (PLA) is renowned for being both biodegradable and industrially compostable. It is appropriate for food packaging since it has comparable mechanical strength and good transparency to PET. PLA's limited use is due to its low resistance to heat and requirement for particular composting conditions. PLA films reinforced with mesoporous silica or Leonardite, which enhance tensile strength, barrier qualities, and antioxidant activity, are examples of recent developments. Because of these improvements, food goods can now have longer shelf lives, making PLA a viable and environmentally friendly substitute for traditional plastics in packaging.

PHB

Bacteria spontaneously create polyhydroxybutyrate (PHB), a biodegradable polyester with mechanical qualities similar to those of polypropylene. Due to its advantages for the environment, PHB is becoming more and more popular for sustainable food packaging, even if its production costs are greater. With the use of nanocomposites, recent developments have enhanced its performance. Addition of magnesium oxide, grape seed oil, or nanoclays improves PHB's toughness, adaptability, and barrier qualities while also boosting its antibacterial and antioxidant capabilities. Products like bread and tomatoes now have a longer shelf life thanks to these changes. With these improvements, PHB-based films offer a viable substitute for traditional plastics in environmentally friendly packaging.

Smart Packaging Technologies

Active packaging is a breakthrough method of food preservation made possible by advancements in edible film production, biopolymers, and nanotechnology. In order to improve safety, preserve sensory quality, and increase shelf life, it incorporates functional elements which interact with food or its surroundings. Nanostructured materials and biophysical components, like nanofibers,essential oils, along with bioactive nanoparticles, allow precise regulation of moisture, gas exchange, and microbial growth.
Structures like electrospun cellulose acetate nanofibers (CANFs) loaded with bioactive compounds are examples of how nanotechnology plays a crucial role. When essential oils of clove and cinnamon were added to CANFs, a fibrous matrix with a high porosity and surface area was formed, enabling the controlled release of antimicrobials and antioxidants. These nanofibers showed good resistance to microbial deterioration while maintaining their organoleptic properties.
Edible films made of natural polymers like chitosan and pectin serve as removable barriers that have the ability to encapsulate and release beneficial substances like natamycin and epigallocatechin gallate (EGCG). These substances improve the performance of edible film in fruit preservation by providing photoprotection in addition to inhibiting microbial growth.
Metal-organic frameworks (MOFs), which have a large surface area and adjustable pore topologies, can also be used to halt fruit ripening after harvest by scavenging ethylene. A higher degree of gas regulation is introduced into the packing matrix by MOFs' capacity to selectively absorb gases.
These technologies, which revolutionise food packaging through edible and biodegradable sheets infused with nanoscale bioactive components, are the result of the convergence of biophysics and material engineering.

Visual detection of protein breakdown in meat and fish is made possible by colorimetric sensors, such as paper-based devices and starch/polyaniline (PANI) films, which change colour in conjunction with spoilage biomarkers like ammonium or biogenic amines. Similar to this, pH sensors that use red cabbage anthocyanins immobilised on bacterial cell membranes allow dairy products' freshness to be tracked in real time based on discernible colour changes.
Additionally, gas sensors are essential for food monitoring. While self-powered oxygen detectors inhibit oxidation-related spoiling by keeping an eye on internal O_2 levels, ammonia-sensitive cellulose fibre sensors identify fish rotting. These innovations promote longer shelf life, lower waste, and improve food quality.

Carlsberg's "Snap Pack" with Colorimetric Sensor Technology

Carlsberg unveiled the "Snap Pack," a novel packaging idea that uses a glue-based bonding mechanism to replace plastic rings on their beer cans, reducing the amount of plastic used by up to 76%. Carlsberg has collaborated with packaging technology companies to investigate the incorporation of colorimetric freshness sensors, which alter colour in response to temperature and freshness conditions, in addition to minimising plastics. The product's labelling or film contains embedded colorimetric sensors. By changing colour in response to environmental changes like temperature swings that might impact beer quality, these sensors give a visual cue as to if the beer has been subjected to unfavourable storage circumstances. This facilitates real-time product quality monitoring for both customers and retailers.
Without changing the recipe or composition of the beer, the Snap Pack principally works on ecological responsibility by drastically lowering the amount of plastic used and improving package transparency. By warning users of possible spoiling or exposure to unfavourable storage circumstances, including temperature violence, which can reduce product quality or raise the danger of microbiological contamination, the incorporation of colorimetric detectors for freshness monitoring provides indirect health advantages to consumers. By reducing the possibility of consuming tainted or spoilt beverages, this technology promotes safer consumption habits and improves product safety in general.

There are still a few potential problems with the Snap Pack's materials. To guarantee food safety and prohibit any hazardous diffusion from packaging into the product, adhesives and sensory components must pass stringent testing. Even though Carlsberg collaborates extensively with regulatory bodies, continuous observation is necessary to completely comprehend potential long-term impacts. Furthermore, even while the Snap Pack successfully cuts down on plastic waste, it ignores the health hazards that come with alcohol use, like binge drinking. Thus, innovative packaging enhances safety and the environment but has no direct effect on the health effects of alcohol.

The CG is also actively working to limit the amount of water used at the breweries. In order to do so, it combines continued efficiency upgrades with investments in recycling wastewater. Some of the highlights of its efforts in 2020 include installing new bottle washers in a brewery in Vietnam, which helped to significantly cut water use, and implementing better water management practices in a brewery in China. In 2020, it began constructing a new water-recycling plant in Denmark, which will halve water consumption at the brewery and cut the amount used to produce each hectoliter of beer from 2.9 hl to 1.4 hl

On the Global Beer Responsibility Day in 2020 in Malaysia, in cooperation with ride-hailing services, it launched an annual campaign to discourage drunk driving by offering discounted rides home from 7 pm to midnight. It also uses alcolocks (locks preventing people from driving when over the legal blood alcohol limit) in almost half of the company vehicles

Effect of Bio Polymers on Human Health

1. Exposure to Chemicals from Additives
Biopolymers such as PLA might have harmful additives(stabilizers, plasticizers, heavy metal catalysts).
These might migrate into food, water, and soil, which could lead to:
Endocrine disruption
Tissue accumulation
Chronic toxicity
2. Pesticide and Fertilizer Residues
Feedstock cultivation (e.g., sugarcane, corn) employs intensive agrochemicals.
Air, water, or food exposure may lead to:
Respiratory issues
Neurological and liver damage
Skin irritation
3. Occupational Hazards
Manufacturing workers are at risk from:
Sulfuric/phosphoric acid (corrosive)
1-Octanol (systemic toxin)
Heavy metal catalysts (toxic and bioaccumulative)
4. Microplastics and Incomplete Degradation
Under real-world conditions (i.e., landfills), such biopolymers as PLA can create biodegradable microplastics.
Such particles can enter the food chain, with unknown long-term health implications.
5. Food Security Impacts
Harvesting food crops for bioplastics can increase food prices and decrease availability, leading to malnutrition and food insecurity, particularly in vulnerable areas.

Results

1. Improvement in Shelf Life:
Chitosan films, especially the ones with essential oils and nanoparticles, had excellent antimicrobial and antioxidant properties. Such films had the ability to increase the shelf life of delicate foods like ready-to-eat fish and strawberries through the prevention of bacterial growth and oxidative deterioration.

2. Enhanced Meat Packaging Performance:
PLA-based vacuum packaging limited the loss of exudates and retained the sensory attribute of beef steaks for 28 days. PLA and Mater-Bi® films were superior to traditional PA/PE films in maintaining meat color and moisture levels.

3. Active and Intelligent Packaging:
Nanotechnology-based materials, such as electrospun cellulose nanofibers incorporated with cinnamon and clove essential oils, provided controlled release of bioactive ingredients. They efficiently preserved fresh fruits against microbial spoilage without compromising visual and textural integrity.

4. Real-time Spoilage Detection:
Smart packaging systems based on colorimetric and pH sensors—like starch/polyaniline films and anthocyanin-based indicators—facilitated visual monitoring of food freshness. They were especially effective for spoilage detection in meat and dairy products.

5. Consumer-Focused Innovations:
Carlsberg's "Snap Pack" innovation, which substitutes plastic rings with glue and incorporates freshness sensors, is an example of sustainability merged with consumer protection. Colorimetric indicators gave visible signals about possible temperature misuse while in storage and transportation.

6. Environmental and Health Considerations:
Although biopolymers decrease dependence on fossil fuels and lower exposure to endocrine-disrupting chemicals, issues exist regarding lack of complete degradation, microplastic generation, and additive leaching in actual applications. Correct end-of-life treatment and regulatory compliance are essential to ensure long-term safety.

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Connecting India for a Safer Food

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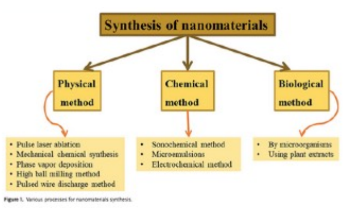

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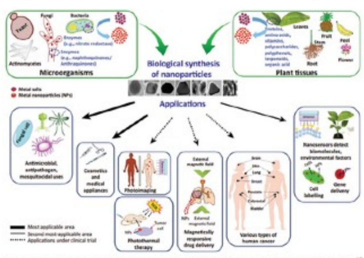

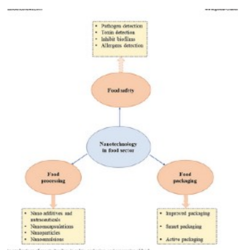

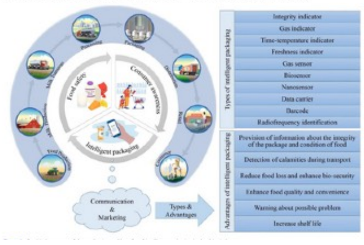

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1. Exposure to Chemicals from Additives

Biopolymers such as PLA might have harmful additives(stabilizers, plasticizers, heavy metal catalysts).

These might migrate into food, water, and soil, which could lead to:

Endocrine disruption

Tissue accumulation

Chronic toxicity

2. Pesticide and Fertilizer Residues

Feedstock cultivation (e.g., sugarcane, corn) employs intensive agrochemicals.

Air, water, or food exposure may lead to:

Respiratory issues

Neurological and liver damage

Skin irritation

3. Occupational Hazards

Manufacturing workers are at risk from:

Sulfuric/phosphoric acid (corrosive)

1-Octanol (systemic toxin)

Heavy metal catalysts (toxic and bioaccumulative)

4. Microplastics and Incomplete Degradation

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