**Plastics in Food Packaging: Trends, Innovations, and Environmental Impact**

**Abstract**

Packaging plays an essential role in preserving, protecting, and distributing food products while maintaining their quality and safety. Among various packaging materials, plastics have become dominant due to their versatility, cost-effectiveness, and ability to provide effective barriers against external factors like moisture, oxygen, and microbial contamination. This review explores the types of packaging materials, with a focus on flexible and rigid plastics, and their application in food packaging. It examines the role of plastics, including polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET), in protecting food and enhancing its shelf life. Additionally, the review discusses the latest innovations in food packaging, such as nanomaterial-based packaging, active and intelligent packaging systems, and the integration of smart technologies like IoT and QR codes. With growing environmental concerns, there is a shift toward sustainable alternatives, including biodegradable and bio-based plastics. The study emphasizes the need to balance food safety, convenience, and sustainability in food packaging.

**Keywords :**Food Packaging; Plastics; Thermoplastics; Sustainability; Smart Packaging

**Introduction**

Foods can be preserved, protected, merchandised, marketed, and distributed with the use of packaging materials. They are crucial in ensuring that these goods are delivered to customers in a healthy, safe manner without sacrificing quality. These items may undergo modifications over time as a result of ongoing interactions between the food and contact with the packing material. Therefore, it is crucial to take into account a number of considerations when selecting the appropriate packaging for a given food product. In general, the packing material can be either flexible or rigid.Glass and plastic bottles and jars, cans, ceramics, wood boxes, drums, tins, plastic pots, and tubes are examples of rigid containers. They offer the food within with physical protection that flexible packaging cannot. Flexible packaging is a broad category of materials that includes papers, foil, plastic films, and various vegetable fibers and textiles that can be used to create sealed or unsealed bags, sacks, and wrappings.

Flexible and rigid packaging materials have been created to provide the essential barrier, inactivation, and confinement qualities needed for effective food packaging, either by themselves or in conjunction with other preservation techniques (Raheem, 2013). The most popular and successful technique for inactivating microorganisms was found to be the combination of heat and stiff packaging materials composed of glass, plastic, or metal (Cutter, 2002). However, alternative methods, such as controlled atmosphere, vacuum, modified atmosphere, active, and edible packaging, can inactivate food-associated microbes in plastic or paper packaging materials (Suppakul et al., 2003). Since early humans began storing and consuming food in a range of naturally occurring, locally accessible containers, major advancements in food packaging materials have made it possible to reduce microbial growth and shield food from external microbial contamination. Over time, packaging materials were created to stop germs from causing food to deteriorate due to exposure to air, moisture, or pH changes related to the food or its surroundings.

Food companies must choose the best packaging material for their products by weighing the benefits and drawbacks of each option, as well as any additional features that might be added based on the food product's end-use characteristics. This review is mainly on the characteristics of plastics, paper as flexible packaging materials and their roles in food quality and safety.

**Packaging**

Goods must be packaged in the modern world from the moment they are created until the conclusion of their lifecycle, including throughout processing and handling. About 2% of the gross national product in developed nations comes from packaging, and the food industry uses the majority of packaging materials (Robertson, 2016). The global packaging market was valued at USD 383 billion in 2000 and is projected to grow to USD 980 billion by 2020 (Sydow, 2018). Packaging materials help to minimize adverse environmental effects while also preserving, protecting, marketing, and distributing foods in an economical way that pleases consumers and business (Marsh and Bugusu, 2007; Robertson, 2018).

Packaging solutions are the result of years of design advancements, some of which were fortuitous. Early societies were self-sufficient and only produced or caught what they required, thus they would eat food straight from the source, negating the need for wrapping materials (Welt, 2020). When packaging became necessary, nature supplied the first materials in the shape of animal organs, woven grasses, and hollowed wood (Welt, 2020; Raheem, 2013). As civilization advanced, newer materials with distinctive shapes—such as pottery, glass, metal, and paper—were employed for particular purposes (Raheem, 2013). Packaging materials come in two varieties: flexible and stiff. Bottles, jars, cans, and tins are examples of rigid packaging, whereas plastic films, papers, foil, cloth and sacks are examples of flexible packaging.

**Types of Packaging**

Packaging can be broadly classified into three main types: primary, secondary, and tertiary packaging, each serving distinct roles within the supply and distribution chain (Robertson, 2018; Welt, 2020; Raheem, 2013; Nurul et al., 2016; Ashok et al., 2016; Kumar et al., 2011; Wikstrom et al., 2014). *Primary packaging* is the first layer of packaging that comes into direct contact with the product itself and is typically what the consumer handles. It plays a crucial role in protecting the product from contamination and damage while also serving as a medium for branding and essential labeling. *Secondary packaging* is used to group multiple primary packages together, facilitating easier handling, transportation, and storage. In many cases, secondary packaging is designed to be shelf-ready, enabling direct placement on retail displays to promote visibility and consumer convenience. Finally, *tertiary packaging* provides structural support for the transport and bulk handling of secondary packaged goods. It includes large shipping containers, pallets, and stretch wraps, ensuring the efficient and safe movement of products through the logistics chain, especially during long-distance distribution.

**Plastics**

Plastics are among the most significant innovations of the new millennium. The field of food packaging has advanced significantly as a result of plastics. The plastics industry is growing at a pace of 4 to 5 percent annually worldwide, whereas it is growing at a rate of 15% in India. Our plastics businesses can now serve international markets, and India has developed the skills necessary to take advantage of opportunities around the world. About 3,915 KT of basic plastics are consumed in India, with polyole-fins (polyethylene, polypropylene, etc.) accounting for the largest amount at 2,640 KT. PVC, PS, ABS, PET, and other materials follow at 850, 210, 65, and 75 KT, respectively. By the end of this decade, India, which currently ranks ninth in the world, is expected to rise from its current position as the second or third largest user of plastic (Raj, 2018). There are over 23,000 small-scale processing facilities and 16 large raw material manufacturers, with a combined sale of about Rs 27,000 crore. In the nation, almost 3 million people rely on plastic products for their livelihoods.
Some beneficial qualities of plastics are responsible for the general growth of the plastics industry in our nation. These materials are adaptable, lightweight, non-corrosive, energy-efficient, long-lasting, and easy to use. Their low cost, attractive appearance, and abundance are the primary drivers of India's industrial boom. Because plastics improve people's quality of life by satisfying the lifestyle demands of all societal segments, the plastics sector is bigger than that of steel and aluminium. Plastics protect the environment and natural resources. India's rapid technological adoption has made it the region with the second-highest rate of economic growth. Agriculture, communications, consumer products packaging, healthcare, infrastructure, transportation, and information technology are the main drivers of this expansion. Plastics contribute significantly to the growth of the nation (Raj, 2018).

Plastics are fluid, moldable, heat sealable, easy to print, and can be incorporated into production processes where the package is formed, filled, and sealed in a single production line. They are composed of large, organic (carbon-containing) molecules that can be formed into a variety of useful products (Marsh and Bugusu, 2007). Plastics' varied permeability to light, gasses, vapors, and low molecular weight compounds is their main drawback. While barrier polymers like polyvinyldene chloride and ethylene vinyl alcohol offer protection against the transfer of gasses, flavors, and odors through the packaging, structural polymers like polyethylene and polypropylene offer mechanical qualities at a reasonable cost. The structural and barrier resins are joined by tie resins, which are co-extrudable adhesive resins.

**Classification of Plastics**

**Thermosets**
The application of heat causes thermosetting polymers to "cure," or harden. Since they cannot be remelted, in order to create items produced from them, the polymer materials must be charged to a mold, which is then heated to create a stiff object with the desired shape. A few of the earliest plastics were phenolics, such as urea formaldehyde polymer and phenol with formaldehyde. In the early days of plastics, both of these materials were widely employed for bottle and jar caps because of their strong resistance to alcohols and solvents. These days, they are hardly ever utilized in packaging. They are primarily utilized in trays and closures as opposed to the main structures used for food packing. They do, however, occasionally appear in applications that require exceptional resilience to temperature fluctuations. Other thermosetting polymers include epoxies and polyurethane.

**Thermoplastics**

Nowadays, the most common plastics used in packaging and a variety of non-packaging uses are thermoplastics. Because they can be readily shaped into an almost infinite number of different shapes by heating them repeatedly, they rule the plastics world. One of the main factors contributing to the widespread use of plastics as food and beverage packaging materials is their simplicity of fabrication and the variety of fabrication techniques available. In addition to enabling the combining of various plastics to achieve special qualities, fabrication has aided in the creation of plastics that are simple to work with on high-speed packaging and printing equipment. Plastics' decreased weight and lower energy requirements for fabrication have resulted in significant cost savings for numerous package solutions.

Thermoplastics account for the largest portion of plastic used in food packaging because they can be economically shaped quickly into any shape required to meet the function of the package and are particularly suitable for recycling and waste-to-energy conversion. Polyolefins (low or high density polyethylene, polypropylene, etc.), polystyrene, polyester, nylon, polycarbonate, and vinyl polymers are the main families of thermoplastics used in food packaging.

**Commonly used plastic materials in food packaging**

A wide variety of plastic materials are used in food packaging, each selected based on its specific barrier properties, mechanical strength, flexibility, and suitability for different food types. Among the most commonly used is polyethylene (PE), which exists in forms such as low-density polyethylene (LDPE) and high-density polyethylene (HDPE). LDPE is favored for its flexibility and moisture resistance, making it suitable for films and bags, while HDPE offers greater rigidity and is commonly used in milk jugs and bottle caps. Polypropylene (PP) is another widely used plastic known for its high melting point and resistance to grease, making it ideal for microwaveable containers and yogurt cups. Polyethylene terephthalate (PET) is valued for its strength, transparency, and gas barrier properties, and is extensively used in beverage bottles and food trays. Polyvinyl chloride (PVC) provides excellent clarity and cling, making it suitable for shrink wraps and stretch films, although its use has declined due to environmental and health concerns. Polystyrene (PS), used in both rigid and foam forms, is applied in disposable cutlery, trays, and containers, especially for ready-to-eat meals. In addition, ethylene vinyl alcohol (EVOH) and polyamide (PA) are often used in multilayer films for their superior gas and aroma barrier functions, enhancing shelf life in vacuum and modified atmosphere packaging. The combination of these materials in multilayer structures allows packaging to be tailored to the specific preservation needs of different food products.

**List 1 : Food Packaging Applications of Common Thermoplastic Materials (Kumar et al., 2016)**

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| --- | --- | --- | --- |
| S.No | **Thermoplastic Material** | **Abbreviation** | **Packaging Applications** |
| 1 | Polyethylene Terephthalate | PET | Water/juice/soft drink bottles, food jars, microwavable containers, plastic films |
| 2 | Polypropylene | PP | Drinking bottles, bottles for milk, food containers |
| 3 | Polyvinyl Chloride | PVC | Plastic bags, frozen food stretch films, container lids |
| 4 | Polystyrene | PS | Takeaway clamshells, meat trays, bottle caps, straws |
| 5 | Low-Density Polyethylene | LDPE | Disposable cups, plates, spoons, bread bags |
| 6 | High-Density Polyethylene | HDPE | Custom packages, grocery bags, water/milk/juice containers, cereal and snack liners |

**Functions and Uses of Plastics in Food Packaging**

Plastics play a fundamental role in modern food packaging due to their unique combination of protective, mechanical, and functional properties. Their widespread application stems from their adaptability to a broad range of food types, shelf-life requirements, and consumer expectations. The primary functions of plastics in food packaging are protection, preservation, containment, convenience, and communication, all of which contribute significantly to food quality and safety across the supply chain. One of the most critical functions is protection against external environmental factors such as moisture, oxygen, light, dust, and microbial contamination. Barrier properties are tailored by selecting specific polymers or multilayer structures—such as polyethylene (PE), polyethylene terephthalate (PET), and ethylene vinyl alcohol (EVOH)—to suit different food preservation needs (Robertson, 2013). These materials help in reducing oxidation, maintaining sensory properties, and extending product shelf life.

Plastics also provide mechanical strength and containment, protecting food from physical damage during transportation and storage. Their lightweight nature contributes to reduced shipping costs and carbon emissions (Marsh &Bugusu, 2007). Furthermore, plastics offer convenience features such as resealability, single-serving formats, and compatibility with microwave or oven heating, aligning with modern consumer lifestyles. The use of plastics varies across food categories. In fresh produce packaging, breathable films are used to manage respiration and delay spoilage. For high-fat or protein-rich products like meat and cheese, high-barrier laminates inhibit oxidation and microbial growth. PET bottles are widely used in beverages for their clarity, impact resistance, and recyclability. Snack foods often utilize metallized films for superior light and moisture protection (Brody, Bugusu, Han, Sand & McHugh, 2008).

In addition to passive protection, plastics are central to active and intelligent packaging systems. Active packaging may contain oxygen scavengers or antimicrobial agents, while intelligent packaging includes sensors or indicators that monitor product condition (Yam, Takhistov& Miltz, 2005). These innovations enhance food safety and traceability, offering added value to both manufacturers and consumers. Despite their benefits, the environmental impact of plastic waste remains a concern. Research into biodegradable and recyclable alternatives is ongoing, aiming to balance performance with sustainability. Materials such as polylactic acid (PLA), polyhydroxyalkanoates (PHA), and starch-based bioplastics show promise for replacing conventional plastics in selected food applications (Siracusa, Rocculi, Romani & Rosa, 2008). Plastics also serve as an important communication medium. Their printable surfaces allow for clear labeling of nutritional information, expiration dates, branding, and usage instructions. Advances in smart and active packaging technologies have further enabled plastics to incorporate indicators for freshness, temperature exposure, or tampering.

**Recent innovations in food packaging**

Recent innovations in food packaging have focused on enhancing sustainability, improving food safety, and enriching consumer engagement. One significant advancement is the development of nanomaterial-based packaging, which incorporates nanoparticles to improve barrier properties, mechanical strength, and antimicrobial activity. For instance, incorporating copper-based nanocomposites into packaging materials has demonstrated enhanced antimicrobial properties, contributing to extended shelf life and improved food safety (Zhao et al., 2018). ​ Another notable innovation is the integration of smart packaging technologies, such as the use of Internet of Things (IoT) devices and QR codes. IoT-enabled packaging allows real-time monitoring of temperature, humidity, and other environmental factors, ensuring optimal storage conditions and enhancing traceability throughout the supply chain (Vermeiren et al., 2017). QR codes on packaging provide consumers with easy access to product information, including origin, nutritional details, and recycling instructions, thereby improving transparency and engagement (Sorrentino et al., 2019).​

Additionally, the use of biodegradable materials has gained prominence as a sustainable alternative to conventional plastics. Materials such as polylactic acid (PLA) and polyhydroxybutyrate (PHB) are derived from renewable resources and offer the advantage of biodegradability, reducing environmental impact (Kumari et al., 2020). For example, PHB nanocomposites reinforced with silver and zinc oxide nanoparticles have shown improved mechanical properties and antimicrobial activity, making them suitable for active food packaging applications (Mittal et al., 2020).​ Furthermore, the incorporation of active packaging technologies, such as oxygen scavengers and moisture regulators, has been developed to interact with the food product or its environment to extend shelf life and maintain quality. These systems can absorb excess oxygen, moisture, or ethylene gas, thereby slowing down spoilage processes and preserving freshness (Kerry et al., 2018).​ Collectively, these innovations reflect a trend toward more sustainable, efficient, and consumer-friendly food packaging solutions that align with contemporary demands for environmental responsibility and enhanced user experience.​

**Conclusion:**

Plastics have revolutionized food packaging by offering practical, cost-effective, and versatile solutions that meet the needs of modern consumers and the food industry. Their ability to protect food from environmental factors and extend shelf life has made them indispensable in food packaging. However, the environmental impact of plastic waste has driven innovation in alternative materials, such as biodegradable plastics and nanocomposites, to reduce ecological footprints. The integration of smart and active packaging technologies, along with advancements in recyclability, is contributing to more sustainable packaging solutions. As the food packaging industry evolves, it is essential to strike a balance between performance, food safety, consumer convenience, and sustainability to address both current needs and future environmental challenges.

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