Original Research Article

Smart packaging for sustainable food waste management: A Review

Abstract

The development of biodegradable packaging for partial replacement of petrochemical-based polymers is influenced by serious concerns regarding the environment and food safety. The purpose of this review is to provide current information on developments in biodegradable packaging materials, as well as the role that nanotechnology and virtual technologies play in the food supply chain. Typical biodegradable materials include polylactic acid, gelatin, starch, chitosan, and cellulose. Tensile strength, rip resistance, permeability, degradability, and solubility are a few characteristics that determine which food packaging materials should be used and how. Microbial enzymatic activities and bioassimilation are two ways that biodegradable films might break down in soil. Blended films are enhanced with nanoparticles to make packaging materials work better.

Introduction:

The population of the world is expected to increase from 7.8 billion in 2020 to 10 billion in 2050 [United Nations, Department of Economic and Social Affairs, Population Division (2019). Food security is under strain from factors like population growth, urbanization, dietary variation, and climate change, which also affects fresh crops after harvest. Fresh product is mostly lost during the postharvest phase (Zekrehiwot et al. 2017). Because of its high moisture content, fresh product is perishable. Postharvest losses (30–50%) of fresh food are typically related to packaging, handling, and storage. It is challenging to track and manage losses in the supply chain due to the bulk size of the product. However, digital advancements in packaging, such as smart packaging, are seen to be appropriate for monitoring and managing postharvest losses. Nonetheless, the ecosystem and climate may suffer if synthetic plastics are used in food packaging [3]. As a result, eco-friendly packaging materials are starting to take precedence. Polylactic acid and starch are prospective materials that could take the place of synthetic polymer films, or plastics used in food packaging. Additionally, edible biofilms can be made from polysaccharides and are compostable (Muller et al. 2017)

A more modern method for creating biodegradable food packaging that is safe for both people and the environment is the creation of edible biofilms. However, a number of obstacles, including climate change, rising consumer safety concerns, and ensuing problems with laws and government regulations, are confronting the food sector (Bader and Rahimifard 2018). The GDP (gross domestic product) of the South African economy is around 2% influenced by the packaging industry. The worldwide need for biobased.

Current scenario of packing in food industry

A more modern method for creating biodegradable food packaging that is safe for both people and the environment is the creation of edible biofilms. However, a number of obstacles, including climate change, rising consumer safety concerns, and ensuing problems with laws and government regulations, are confronting the food sector. Food packaging has a crucial function in the modern food industry. New food packaging technologies seek to meet consumers and industrial's demands. Changes related to food production, sale practices and consumers' lifestyles, along with environmental awareness and the advance in new areas of knowledge (such as nanotechnology or biotechnology), act as driving forces to develop smart packages that can extend food shelf-life, keeping and supervising their innocuousness and quality and also taking care of the environment. Numerous studies show the great possibilities of biodegradable and biobased polymer materials. The All India Food Processors Association projects that urbanization, changing consumption patterns, and growing disposable incomes would propel the country's food and beverage packaging sector to a $86 billion market by 2029.According to Chairman Prabodh Halde, the market is shifting towards natural, organic, vegan, and GI-tagged items, as well as health foods and environmentally friendly packaging. (packaging industry: 'Growing demand to help Indianfood, beverage packaging industry to reach USD 86 bn by 2029' - The Economic Times(indiatimes.com)Accessed on 18 December, 2023)

Role of Packaging:

A million or more food packaging materials are expected to be produced by 2020, tons annually (Cerqueira et al. 2016). Consistent with the packing material considered the primary element of sustainable development Goal 12 was thematically centred (ocean, climate action). action, food loss and waste, ocean plastic pollution, and sustainable transportation), which are associated with sustainable consumption and output. Packaging for food offers protection. Storage and storage of food by erecting a physical wall to prevent contamination from foreign objects and environmental influences. This ultimately helps. to increase the food product's shelf life. Additional roles consist of ease of use, physical and mechanical strength, and through product labelling, communication

Improved income, livelihood, and food security are the outcomes of the postharvest strategy of limiting waste through the packing of tomatoes along the supply chain (Sibomana et al. 2016). An increased shelf life is also achieved. The latest advancement in innovative food packaging is propelled by the needs of consumers for shelf life, ease of use, and ready-to-eat food quality preservation and stability as in (Mangaraj et al. 2019). Petroleum polymers don't break down too much, and resulting in ecological flaws. Moreover, materials made of polymer plastics could take more than a century to break down.

Hence, there are developments to replace petroleum-derived plastic with biodegradable materials. The innovation and development of food packaging from renewable, compostable, and biodegradable to active and intelligent packaging were reported (Mahalik and Nambiar 2010; Ivankovic et al. 2017).In addition, barrier proper- ties, compatibility materials, and shelf life extension properties of the innovative packaging determine selection and utilization (Ivankovic et al. 2017). The environmental safety concerns are limiting the use of plastic films for packaging in the food industries. Consequently, biopolymer films are receiving attention due to their biodegradable properties.

From 2012 to 2017, the use of biodegradable materials increased at a compound annual growth rate (CAGR) of 15–20% in the markets of North America, Europe, and Asia (Chbib et al. 2019).

However, market data for Africa is lacking. According to Atarés and Chiralt (Atarés and Chiralt 2016), essential oils were used in biodegradable food packaging sheets in Spain to create bio-based packaging that may have positive effects on health (antioxidants and antibacterial qualities). The lipid content of essential oils can enhance the mechanical, optical, and structural qualities of packaging films while also reducing the permeability of water vapor in hydrophilic materials. Extended shelf life was achieved by the biodegradable packaging films that Finland developed and tested on tomato fruit for preservation purposes.

Furthermore, reports indicate that biodegradable plastic film is produced extensively in Nigeria by combining biodegradable polymer ingredients with cassava starch. Fresh tomato postharvest losses were reported to be 9.50, 9.80, and 10.04% in sub-Saharan African countries' eastern, central, and southern regions, respectively (Kantola and Helen 2001). Kenya, South Africa, and Nigeria recorded 10.10, 10.20, and 13.40% postharvest losses, respectively. However, professional or new tomato growers were able to reduce postharvest losses by using recyclable cardboard boxes of

different sizes, bulk containers, and plastic

Food packaging films are made from raw plastic polymer, biopolymer, and biodegradable materials using lamination, casting, coextrusion, or coating techniques.

Importance of Packaging:

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Biodegradable packaging:

Extended shelf life was achieved by the biodegradable packaging films that Finland developed and tested on tomato fruit for preservation purposes.(Ali et al. 2010). provided evidence of the use of gum in Malaysia. Gum arabic as a covering layer that is edible to prolong the shelf life and tomato's quality after harvest. Edible coatings made of starch potatoes that were native to Colombia were used on Andean South American blueberry, a wild fruit endemic to the region, producing a decreased breathing rate of about 27% (Medina-Jaramillo et al. 2019). Nevertheless, prior works suggested more investigation centered on the enhancement of the biodegradable films' mechanical strength similar to petroleum-based polyfilms. Food packaging film is made from bio-derived monomers such polylactic acid as well as bio-polymers including gelatin, starch, and cellulose (Abdul Khalil et al. 2018). The substances produced by microorganisms include pullulan, cellulose, xanthan, and curlan. The natural polymer chitosan is produced by deacetylating chitin, the second most prevalent biopolymer in nature after cellulose. It is nontoxic, edible, and biodegradable. It is recommended to add various additives to the biodegradable film in order to enhance its qualities (Suyatma etal. 2004). Proteins and polysaccharides are examples of hydrophilic material components that might stabilize edible biodegradable films.Bioplastics are presented as a greener option to traditional petroleum-based plastics. Despite their low market share, expected growth suggests increasing popularity. The term encompasses materials made from renewable sources, those designed to degrade naturally, or both (Hussain et al. 2024).

Innovations in Packaging Technology

The technologies used in food packaging include biodegradable coatings, controlled packaging, adaptive, intelligent, and active packaging. Packaging that works. Using antimicrobial ingredients is a feature of cutting-edge food packaging technologies like packaging that is proactive and clever (Garcia-Garcia et al. 2013). offer details regarding the quality during storage and transportation.

The polymeric materials derived from petroleum are typically used in packaging that is active (Azeredo et al. 2019). Intentionally adding active materials to packaging material or packaging headspace extends shelf life by allowing for the controlled release of antimicrobial compounds (Zhang et al. 2015). In response to consumer demand for fresh produce with higher quality and safety, active food packaging was created (Garcia-Garcia et al. 2013). Active packaging for tomato fruit preservation increased safety, preserved sensory qualities, and increased shelf life (GarciaGarcia et al. 2013). In order to create active packaging materials and help preserve food, essential oils with antimicrobial and antioxidant properties are added to food packaging films.

Intelligent packaging is defined aspackaging that includes internal or external indicators that provide details about the product's safety and quality history (Zhang et al. 2015). Smart or intelligent packaging technologies provide the chance to record and detect changes in the packaged product and its environment (Vanderroost et al. 2014). Along the supply chain, intelligent packaging keeps track of the food's past (Gherardi et al. 2016). For example, (Bartkowiak et al. 2016) reported that the time-temperature indicators based on lactic acid provided historical data on the quality and time temperature of food based on lactic acid. Therefore, products derived from tomatoes and tomatoes themselves that are naturally acidic can benefit from this application. Some of these technologies did, however, become commercially available, in part because of their higher initial costs.

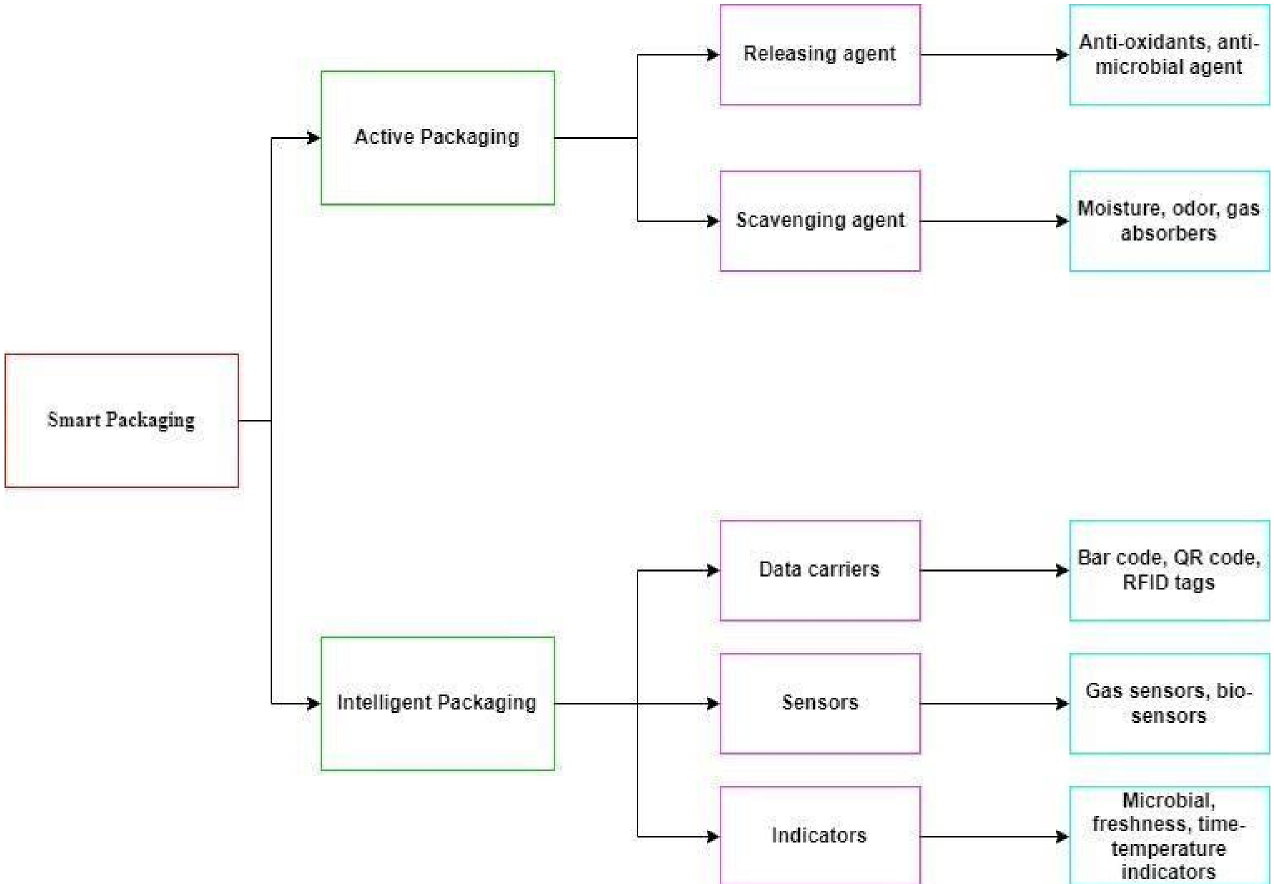

Figure1: Classification of smart packaging systems

Smart technology in various sectors:

India has been a potential exporter of fresh fruits and vegetables and has exported fruits and vegetables with a net worth of 750.7 and 767.01 USD million, respectively during the year 2021(APEDA 2021; Apjok et al. 2019). Fruits and vegetables are highly perishable products that necessitate appropriate internal packaging conditions such as temperature, gas composition, and humidity to keep up the quality as well as to preserve the shelf□life (Araguez et al. 2020) *Salmonella* species, *Shigella*, *Staphylococcus*, *Bacillus cereus*, *Campylobacter jejuni*, *Clostridium botulinum*, *Escherichia coli*, *Listeria monocytogenes*, and *Vibrio cholera* are among the bacteria that can be found in fresh fruits and vegetables. Inadequate handling and processing procedures, particularly during transit, are primarily to blame for the invasion of microorganisms (Balasubramanian et al. 2009). One of the main challenges, aside from infections, is managing postharvest metabolisms such as respiration, ripening, and senescence. Unlike other culinary commodities, fruits and vegetables require packing materials that permit gas exchange in order to preserve their quality (Barbosa et al., 2021). Controlling oxygen, ethylene, and moisture content while also preventing the growth of microbes is the main goal of active packaging for fruits and vegetables (Bodbodak and Rafiee 2016). Because temperature has an impact on the product's respiration, ethylene

synthesis, and transpiration rates, it is a crucial parameter to keep an eye on. The respiration rate is predicted to increase in response to the elevated temperature, hastening the process of deterioration. However, fruits that are susceptible to physiological harm at low temperatures include mangoes and bananas (Ghaani 2016; Goodarzi 2020). Time-temperature indicators (TTI) are affixed as labels to denote many temperature-dependent reactions, including the potential endurance of bacteria, denaturation of proteins, and irreversible changes in fruits and vegetables due to chemical and enzymatic processes (Ghoshal 2018). According to Ghoshal (Thirupathi et al. 2023), timetemperature monitoring devices are suggested for both fresh and slightly processed fruits and vegetables. The utilization of oxygen absorbers has proven effective in mitigating the oxidation of dried sweet potato flakes contain βcarotene, which enhances the tomatoes' shelf life and preserving their nutritional quality in particular, the vitamins found in most fruits and produce (Cruz et al. 2012). As an illustration, the rate of loss of ascorbic acid and the orange's rate of oxidation has been found to be minimal when filled with oxygen. The parameters that consumers notice are flavor and scent. Taste perception and flavor are implied by the existence of fragrant substances.

When food deteriorates, volatile odor molecules like amines, sulfides, and aldehydes are released and accumulate, which eventually lessens the distinct aroma that fruits and vegetables have. Odor absorbers have been incorporated into odor-proof packaging systems (Yildirim et al. 2017). A measure of freshness called ripeness can be challenging for customers to assess. As a result, businesses have developed potential ripeness sensors that allow consumers to determine the ripeness state by changing color in response to the volatile molecules released by the product (Dutra et al. 2016). For example, methyl red-based packaging has been developed to monitor strawberry ripeness. During the ripening process of strawberries, esters are formed, which causes a rise in pH, due to the formation of esters during the ripening of strawberries resulting in color change (Emamifar 2020; Kuswandi 2013).

Natural antioxidants like vitamins C and E that are incorporated into packaging films minimize oxidative reactions, which include rancid odor development and color changes in fatty fish (Biji et al. 2015) The rate of rancidity brought on by lipid oxidation, myoglobin oxidation, moisture loss, moisture accumulation, and pathogenic microorganisms on the surface of coated meats is decreased when active ingredients are incorporated into packaging materials or edible films (Kerry 2012;

Kerry 2014). A Lexington, Massachusetts-based company called "Food Quality Sensor International" has introduced the "SensorQt," a stick-on indicator label that can be applied to the inside of meat and poultry packaging to give consumers a clear indication of the freshness of the product (Pocas et al. 2008).

Nanotechnology plays a crucial role in controlling food spoilage and contamination by enhancing the barrier properties of packaging materials. Nanomaterials can create protective barriers that prevent the entry of oxygen, moisture, and contaminants, reducing the risk of microbial growth and spoilage (Kulkarni et al. 2024).

Food packaging materials must abide by certain rules established by the national regulatory body in question. The FDA (Food and Drug Administration) in the United States has approved the regulatory standards for the various types of substances incorporated in food packages based on the intended use and the benefits offered (Madhusudan 2018; Mary 2020) The regulatory requirements vary by nation and address different problems related to their use in packaging. The Food Safety Base Law of 2003 and the Japanese Food Sanitation Law of 1947 serve as guidelines for the use of smart packaging in the Japanese market (Mexis and Kontominas 2014).

The Canadian regulatory framework for smart packaging is governed by the Health Products and Food Branch (HPFB) system, while the Federal Food, Drug, and Cosmetic Act governs the United States regulatory (Drago et al. 2020). Particular migration limits, general migration limits, and toxicology should be evaluated, and the outcome must adhere to the set parameters for the direct and indirect food components present in the packaging material (Schilter 2019; Shruthy

2020). Consideration should be given to identifying an inert material when devising sensors and packaging based on nanomaterials

The guidelines should also be followed by the materials chosen, presented by a number of international regulatory organizations broad. The sensors ought to be placed outside the surface of the container to prevent food and the movement of materials (Taoukis and Tsironi 2016). A technique for comprehending consumer requirements and expectations is to conduct surveys. These surveys also enable the analysis of consumer complaints and the subsequent development of solutions. Future studies must focus more on consumer surveys as the current studies are limited to demographic and socioeconomic conditions (Young and Bremer 2020). The future forecasts the elevated acceptance and commercialization of smart packaging systems due to the enforcement of regulations that ensure efficiency and safety.

Smart packaging and sustainability

The food sector has been using plastic packaging extensively for approximately 50 years because of its many benefits. Being able to be stiff (bottles, jars, cartons, and cases), thermoformed (food trays), or flexible (woven mesh, multi-layer sheets), they are affordable, practical, lightweight, and incredibly adaptable. As a result, they have supplanted other conventional materials including cardboard, paper, glass, and metals (such as steel, aluminium, laminated, and tinplate). As of late, they account for 37% of the materials used in food packaging (Food Packaging Forum 2015) Because most of these materials are non-biodegradable, derived mostly from petroleum, and damage the environment during manufacturing and disposal, their widespread use has resulted in severe environmental concerns on a global scale. The market is evolving due to the creation of new environmentally friendly packaging and creative packaging ideas. Utilising renewable and biodegradable materials is a fantastic way to preserve the environment while adding value to discarded goods and industrial waste (Cazon et al. 2017)

Conclusion:

There is a growing need for biodegradable packaging materials to take the place of synthetic plastic. The global need for food and energy resources, as well as changes in legislation and policy, all have an impact on the development of biodegradable packaging. The biodegradable materials have poor characteristics (low transparency and high brittleness). Nevertheless, brittleness and other physical characteristics can be enhanced by the use of nanocomposite ingredients. Studies examining the interactions between food products and polymers are scarce. Furthermore, there aren't many studies that identify toxicities linked to ingredients migrating globally from a biodegradable package into food. A significant amount of data would be needed if the food industry were to use digital platforms to meet the 4IR (The Fourth Industrial Revolution) targets. When compared to other food products, the microgravity environment presents significantly more practical challenges for the deployment of smart packaging systems for space food. Compared to beverages and baked goods, the use of smart packaging technology is more appropriate for highly perishable goods like fruits, vegetables, meat, poultry, milk, and milk products. Customers need to be made aware of the benefits of smart packaging systems and dispel any myths about the risks they pose. Surveying consumers is one way to understand their needs and expectations. These surveys also make it possible to analyze customer complaints and then create solutions based on those findings. Since the current studies are restricted to socioeconomic and demographic factors, future research has to concentrate more on consumer surveys.

The future also holds the promise of enhanced smart and interactive materials, such as sensors that can detect food deterioration, increase shelf life, or improve freshness, all while decreasing food waste and boosting food safety. Overall, the prospects for sustainable food packaging materials are promising, and continuing research, development, and acceptance of novel solutions will be important in building a more sustainable and circular economy in the food business.

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