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Innovation in Packaging Industries: Packaging of Agricultural and Food Products

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ABSTRACT

The development of the packaging industry in the agricultural and food industries can not only have a significant impact on increasing the shelf life and preserving the quality of these products but will also increase the economic value and improve the marketability of these products. This review article attempts to introduce innovations in the packaging industry and point out important factors in producing suitable packaging for agricultural and food products. Agricultural products are still alive in the post-harvest stages, meaning they breathe (consume O_2 and release CO_2), which this behavior is unique to each product. Therefore, to package such products, it is necessary to evaluate their behavior during the post-harvest and processing periods and consider packaging conditions appropriate to that behavior for the product. The use of films equipped with Nanoparticles (Nano clay, Nano silica, Nanosilver, etc.) can improve the properties of packaging films and make them suitable for preserving food and agricultural products. On the other hand, creating an atmosphere and injecting gases appropriate to the conditions of the product inside the package will help control the respiration rate and delay the aging and spoilage of the product. Edible and non-edible coatings can also be useful in maintaining the quality of agricultural and food products by creating a protective layer around the product and controlling the respiration rate and enzymatic activities. Also, a combination of the methods described may improve the storage conditions of some agricultural and food products by intensifying the positive effect of each.

1. Introduction

According to the FAO report, 30-50 % of foods and agricultural products is wasted annually in the world (Anonymous, 2017), due to inappropriate packaging, raw materials, transportation, and storage conditions. In Iran, about 40 percent of food and agricultural products are lost as post-harvest waste (Keshavars et al., 2016). Among them, the largest share of waste is accounted for by packaging, which, due to its inappropriateness, causes food to become unusable and spoil, which in turn increases the amount of waste. Packaging also affects other factors of food and agricultural waste. Accordingly, by using packaging that improves storage conditions, the quality and shelf life of food can be increased and the amount of waste can be reduced. On the other hand, food safety is a major issue today and it is essential that it does not endanger the health of the consumer during use. Many methods have been proposed to prolong the shelf life and preserve the quality of agricultural products during storage, the most important and efficient of which are the following (Kim et al., 2006): Active packaging, nano packaging, modified atmosphere packaging (MAP), coatings, control of storage temperature. This study evaluates new methods of packaging food and agricultural products that have been studied in recent years.

2. NANO Packaging

In recent years, plastic packaging raw materials have replaced cellulose raw materials, so the development and evolution of plastic packaging for ready-made foods, frozen foods, dairy products, soft drinks, bread, and chocolate has become more necessary and important in terms of consumption (Huang & Chen, 2012).

In this regard, among plastic materials, polyethylene and polypropylene (homo-and copolymers[1]) are preferred as a layer in contact with food in single-layer, multilayer, and coextruded (produced by extrusion) packaging. The advantages of using these materials include: chemical stablility, minimal reaction with most foods, good moisture

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1. If a polymer consists of only one kind of monomers then it is called a homopolymer, while a polymer which consists of more than one kind of monomers is called a copolymer.

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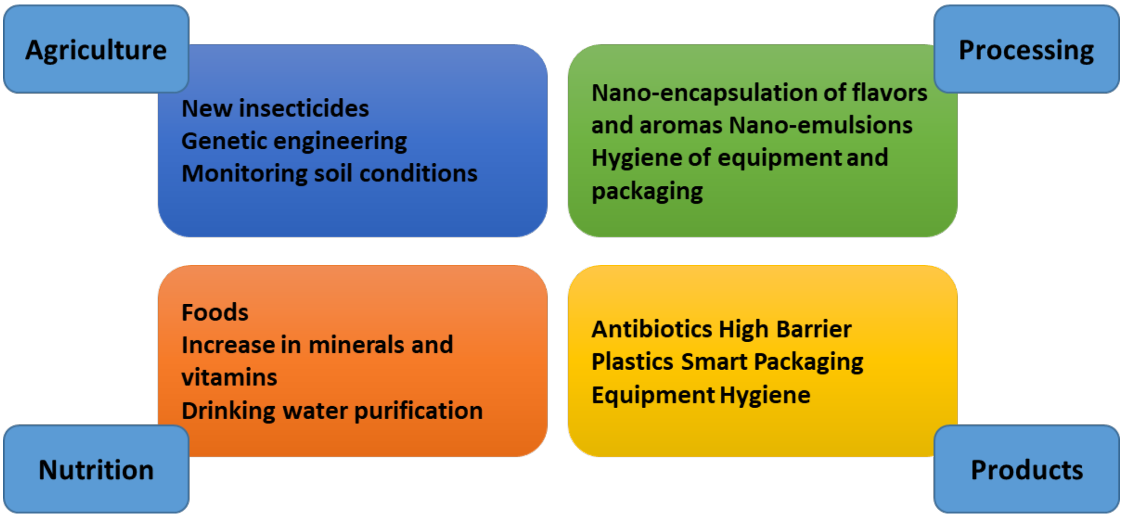

Fig. 1. Potential applications of nanotechnology in food and agriculture

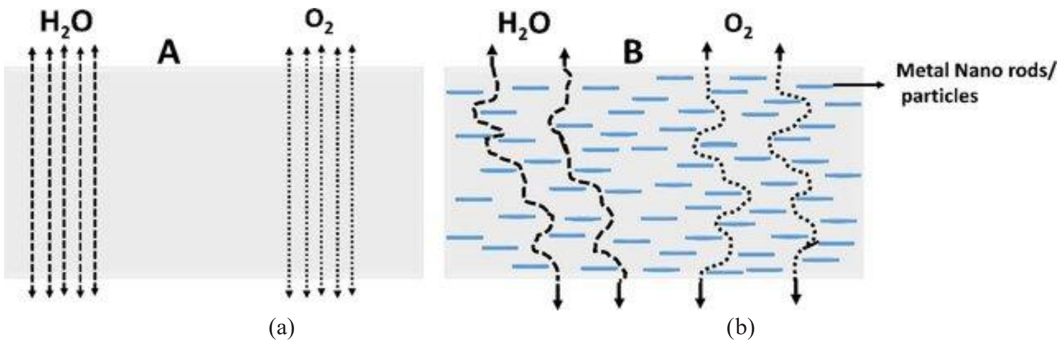

Fig. 2. Gas flow path through (a) Nano (b) conventional packaging film

protection, and the ability to be heat-sealed. On the other hand, if these materials are used, small amounts of residual solvents, monomers, plasticizers, inhibitors, or materials released from molds may enter packaged foods, and flavor compounds cannot penetrate the packaging (Huang et al., 2019). Nanotechnology involves the characterization, fabrication, or manipulation of structures, devices, or materials that have at least one dimension between 1 and 100 nanometers in length. When the particle size is reduced to this size, their physical and chemical properties will also change significantly. The potential use of nanotechnology is now recognized in virtually every sector of the food industry, from agriculture to materials processing, food packaging, and food supplements, as fully illustrated in the diagram presented in Fig. 1 (Carlson et al., 2008).

Nowadays, the food packaging industries use a type of plastic coating, which produced by nanoparticle technology. The nano fillers are dispersed in the polymer matrix, which affects the protective and barrier properties of the homogeneous polymer layer. First: since O_2 is the main controlling factor in food packaging (causes spoil of the fat of food and agricultural products and also changes their color), in new films, nanoparticles are placed in a zigzag pattern and act like a barrier to prevent O_2 from penetrating. In other words, the path that the gas must travel to enter the package becomes longer (Fig. 2). Second: making changes in the polymer matrix, the amount and type of nano filler, also has a positive effect on the properties of the protective layer.

The most used nanofiller materials to produce nanofilm are as follows (Busolo et al., 2010; Jiang et al., 2013; Gholami et al., 2017):

Nano clay and nano silicate plates
Metal nanoparticles
Silica nanoparticles (SiO_2)
Carbon nanotube
Graphene
Starch nanocrystalline
Nanofiber based cellulose
Chitin or nanoparticles Chitosan

3. Gases Inside the Packages

Fruits and vegetables breathe even after harvest. The breathing rate of fruits and vegetables is much higher than the seeds. In vegetables and fruits due to the enzymatic and metabolic activities, the product begins to ripen, resulting in the production of ethylene gas, accelerating the process. During the ripening process, the atmospheric conditions around the fruit, first improve the quality of the fruit but rise rapidly. This biochemical and metabolic process can be modified by changing the conditions around the product. To improve the packaged product conditions and control atmosphere and in-house conditions some methods have been presented in recent years, that in addition to extending the shelf life of the products, also improve the quality of the products and cause it to market. These methods were:

3.1. Vacuum Packaging

In which the air is completely removed from the package before packaging. The main objectives of vacuum packaging are to deoxygenate the package, prevent the growth of aerobic organisms, reduce the size of the package, and prolong the shelf life. For materials that are damaged by the lack of oxygen or during the vacuum packaging process, instead of vacuum packaging and deoxygenating the package, the package is filled with nitrogen gas (Jiang, 2013).

3.2. Modified Atmosphere Packaging (MAP)

The concept of a modified atmosphere for packaged food and agricultural products includes a modified atmosphere space by vacuum and gas injection (nitrogen, oxygen, and carbon dioxide) in order to control chemical, enzymatic, and microbial activities; in other words, in this method, the air is removed from the packaging and the package is re-filled and gasified with gases whose mixture is known. The design and determination of the atmosphere inside the package depends on the properties of the product. The composition of gases inside the package and the rate of product respiration will be affected by the storage temperature and the atmosphere inside the package. Achieving the right balance of atmosphere within the package is based on the respiration of the product and the permeability properties of the packaging film. In fact, the required atmosphere is created passively by the consumption of oxygen and the production of carbon dioxide during the respiration process. The MAP method has the advantages of reducing respiration, reducing ethylene production, and reducing sensitivity to ethylene. It delays tissue softening and changes in fruit composition and reduces adverse physiological symptoms and fruit damage (Gholami et al., 2020). Carbon dioxide is most commonly used in MAP due to its favorable properties. This gas helps preserve vitamins in meat products, lowers the pH of the environment, acts as an antimicrobial, and reduces their activity. It also delays the drying of the product and increases its freshness by absorbing water and hydrating the cell walls. Of course, CO_2 itself is considered a preservative and is absorbed to a small extent by the surface layer of the food, which will not affect the condition of the product. The use of the MAP method has significant sensitivities that, if not observed, can have a negative impact on the quality and preservation of the product, including 1. A mistake in the gas composition can cause the product to crush or cause leakage in the container. This problem can be controlled by correcting the gas composition and using an absorbent paper layer at the bottom of the container. 2. The size and dimensions of the packages are very important in this method because the interaction of products inside a package can accelerate the spoilage process of the product. The range of gas compositions for some products has been suggested in various studies, some of which are given in Table 1. (Gholami et al., 2020; Sandhya, 2010).

Table 1. Suggested gas composition for some agricultural products

Products	O_2 %	CO_2 %	N_2 %
Mushrooms	3-21	5-15	64-92
Strawberries	5-10	15-20	70-80
Apples	1-2	1-3	95-98
Banana	2-5	2-5	90-96
Kiwi	1-2	3-5	93-96
Oranges	5-10	0-5	85-95
Tomatoes	3-5	0-3	92-97

3.3. Modified Atmosphere/Modified Humidity Packaging

In this method, in addition to modifying the atmosphere inside the package by injecting a specific combination of oxygen, carbon dioxide, and nitrogen gases, moisture absorbers, or in other words, humidity controllers, are also embedded inside the package to control the conditions and moisture content of the package within a specific range during the storage period (Lin et al., 2017).

4. Active and Smart Packaging

Smart packaging is a type of packaging that reacts to changes inside the package and informs the consumer about the quality of the contents inside the package. Active food packaging uses more dynamic methods to maintain product preservation, in addition to delaying environmental factors. In recent years, attention has increased to active packaging in food production, which is due to the fact that this type of package, compared to the conventional type, is not only responsible for containing and protecting food and agricultural products from external factors, but also has other advantages, such as helping to increase the shelf life of the desired material by using absorbent agents (moisture and oxygen absorbers), agents that release various compounds (ethanol, chlorine dioxide), heating and cooling the food, and the possibility of determining the shelf life of materials using various sensors and reagents, such as freshness and integrity reagents of the package and the product inside the package. Oxygen absorber systems can be used appropriately to completely remove oxygen after vacuum or MAP. The use of these absorbers within the packaging controls the quality changes of sensitive food and agricultural products (Uba et al., 2020). Oxygen absorbers are effective in preventing discoloration, and mold spoilage in high-moisture and frozen products. The main cause of microbial spoilage of many refrigerated foods is microbial growth on the surface of the product. The use of antimicrobial agents in packaging is beneficial to prevent the growth of microorganisms that may be present in the packaged food or packaging material, thereby increasing shelf life. Studies have shown that the use of antimicrobial films is more effective than the direct addition of antimicrobial agents because the antimicrobial compound is slowly released from the packaging surface into the food and is maintained at the concentration required to prevent microbial growth (Silveira et al., 2007). Antimicrobial films should be effective against a wide range of microorganisms at low concentrations and should not cause any change in the sensory properties of the product (Azlin-Hasim et al., 2015). Types of antimicrobial compounds include alcohol, bacteriocins, enzymes, organic acids, and polysaccharides. Antimicrobial films are divided into two categories: Films with an active antimicrobial agent on the surface of the foodstuff. Films with the effect of preventing the growth of microorganisms on the surface of the foodstuff without transferring to the surface of the product.

5. Coating Types

Today, food consumers are demanding healthier, higher quality, and longer shelf life food additives. These demands have led to a renewed interest in the use of natural materials in food preservation and agriculture. Today, the use of natural edible coatings in various food products has attracted attention as materials with antioxidant and antimicrobial properties (Cheng et al., 2022). Biopolymers extracted from various natural products such as starch, cellulose derivatives, chitin, chitosan, gums, proteins (of animal and plant origin), and fats are used to prepare films and thin coatings to cover fresh or processed food and agricultural products in order to increase their shelf life and improve the storage quality of those products. The use of edible coatings as modern technology, in addition to having benefits such as edibility, acceptable appearance, environmental compatibility, and cheapness, protects food from physical, chemical, and mechanical damage and acts as a barrier against gas exchange, moisture and microorganisms and maintains the quality of the product during the post-harvest stages until the product reaches the consumer (Joerger, 2007; Kerry et al., 2006; Vásconez et al., 2009) .Various coatings are used in the food industry. The most common and widely used coatings are: Plant extracts, Polysaccharides, Waxes, and Chitosan.

5.1. Plant Extracts Coating

The use of natural plant extracts as natural and healthy coatings, in addition to creating a suitable taste and smell, has antimicrobial properties and especially antioxidant properties in foods containing fat. In recent years, the use of plant products such as seed, leaf and shell extracts of some plants, fruits, and spices such as grape extract, almond kernel powder, peanut shell, potato peel, green tea leaf, plum extract, rice bran, ginseng, garlic, onion, olive leaf extract, strawberry, ginger, thyme, rosemary, cloves, coriander, basil, aloe vera, mustard and pepper has been used in the coating of agricultural and horticultural products and meat products (Brannan, 2009; Kim et al., 2006).

5.2. Polysaccharides

Edible coatings are generally classified as protein, polysaccharide, lipid, or a combination of these. Polysaccharide coatings are used to delay the loss of moisture in some foods in a short period of time. Polysaccharide edible coatings can delay the ripening of fruits and extend their shelf life without creating severe anaerobic conditions. Alginate, pectin, carrageenan[1], dextrin[2], starch, cellulose and its derivatives, arabinosilanes, and chitosan are among the most important polysaccharide coatings. Pectin is an important component of the cell walls of plants, especially ripe fruits, and a complex polysaccharide with a high molecular weight. Edible coatings made from pectin and its derivatives have good barrier properties against oxygen and oil penetration, but due to their hydrophilic nature, the permeability of water vapor in these coatings is relatively high (Vásconez et al., 2009). Starch also has advantages as a polysaccharide coating, including its edibility, cheapness, and renewable nature. However, the resistance of starch coating to moisture is low. The use of hydrocolloids in the composition of this coating will improve its elasticity and properties.

5.3. Waxes

Waxing or greasing is the process of applying a thin coating of wax to a number of fruits (such as citrus fruits) and vegetables (such as peppers and cucumbers) to prevent moisture loss and wilting of the product. It also has a positive effect on the appearance and marketability of the product. The compounds used in the process of producing wax for agricultural products are often a mixture of vegetable and petroleum waxes, and usually a combination of paraffin and carnauba wax. Paraffin wax controls evaporation well and carnauba wax has good transparency, which is why they are used as a complement to each other. Among the waxes used in

1. The generic term for a family of viscosifying and gel-forming polysaccharides that are extracted from specific types of red seaweed
2. A group of low-molecular-weight carbohydrates produced by the hydrolysis of starch and glycogen.

coating, polyethylene waxes, synthetic resins, and emulsifiers can be mentioned. These compounds include fungicides and substances that prevent germination and aging of the product during the storage period (Vásconez et al., 2009).

5.4. Chitosan

Chitosan is a natural polymer obtained from the distillation of chitin. Chitin is abundantly found in the shells of crustaceans (crabs and shrimps). Chitosan has many applications in the food industry and is the second most abundant natural polymer after cellulose. This polysaccharide has effective properties such as antimicrobial, antifungal, and antioxidant properties. Chitosan is non-toxic, biodegradable, and environmentally friendly and also limits the growth of many bacteria due to its antimicrobial properties. On the other hand, it can be used as an edible coating in fruits and vegetables due to its suitable mechanical and biochemical properties and non-toxicity. The functional properties of chitosan include the ability to form a film, adhesion properties, absorbency, and purification. Chitosan is a dietary fiber that is widely used in the food, medical, pharmaceutical, dye, textile, cosmetic, and hygiene industries (Shahidi & Abuzaytoun, 2005).

6. Literature and Future of Packaging

In recent years, researchers in this field have conducted a lot of research on the effects of different packaging conditions on the shelf life, quality, and properties of agricultural and food products during storage. Table 2 presents recent research on agricultural and food product packaging.

It is expected that more extensive research will be conducted in the field of innovation in the food and agricultural packaging sector in the coming years. In addition to prolonging the shelf life and preserving the quality of the product during the storage period, which leads to the customer benefiting from a healthier and higher quality product, the use of new technologies in packaging can also make the customer aware of the product's condition at the time of purchase and consumption. The use of packaging with films equipped with nanoparticles, along with an innovative structure that is designed to suit the environmental and respiratory conditions of the product in question, as well as designing the atmosphere inside the package according to the product's respiration rate, will have a significant impact on the preservation of agricultural products. Active and smart packaging will be more important in the future. In addition to maintaining quality and increasing shelf life, these packages must have warnings for the customer. In the current situation, the production and expiration dates of edible products are indicated on them. While in smart packaging, it is expected that the conditions of the product will be provided to the consumer on a daily or even instantaneous basis so that consumers can choose between various products with peace of mind and full awareness of the conditions of the product they are purchasing.

7. Conclusions

According to the studies conducted in this research on the packaging of food and agricultural products, several important and essential points can be mentioned in this regard: Packaging of agricultural products under any conditions can have a positive impact on economic value and marketability. Given the impact of packaging conditions on product characteristics, it is necessary and essential to choose packages that have the most positive impact. Packages produced with nanotechnology and equipped with nanoparticles, due to their internal structure and control of the respiration rate and the passage of various gases, can maintain quality and delay the aging process of the product. The use of specific gases inside the package, appropriate to the characteristics of the desired product, also has a direct impact on the breathability of the product and its characteristics by controlling the conditions around the product. In addition to the use of nanofilms and modifying the atmosphere inside the package, the use of edible and non-edible coatings will also play a significant role. Combining new methods and using smart packaging to prolong the shelf life of food and agricultural products and improve their quality during the storage period, as well as providing the customer with full awareness of the conditions of the product inside the package and making informed choices, will be indicators in improving the packaging industry.

Table 2. Summary of the state-of-the-art of literature

Packaging and storage condition	Finding of research	Reference
Chitosan-metal and metal oxide nanocomposites for active and intelligent food packaging	This review delves into the physicochemical, mechanical, sensing, and antimicrobial properties of chitosan nanocomposite as an innovative food packaging material.	(Jogaiah et al., 2025)
A novel edible coating based on cress seed (CS) mucilage enhanced with probiotic *Limosilactobacillus reuteri* VTC 864 bacteria (LR)	The strawberries coated with LR-loaded CS mucilage exhibited notably lower weight loss, decay percentage, and total fungi counts, along with higher sensory scores compared to the control group. The CS mucilage coating, particularly in conjunction with LR, demonstrated remarkable effectiveness in preserving the physicochemical, bioactivity, and safety properties of strawberry samples.	(Rahmati-Joneidabad et al., 2025)
The chitosan-based films for sustainable food packaging applications	The contribution summarizes the various strategies adopted to overcome inherent drawbacks and improve the properties of chitosan-based films, with special regards for blending with natural and synthetic biopolymers.	(Haghighi et al., 2020)
An active coating capable of removing methylmercury from liquid food media	The methylmercury adsorption ability of the coatings were preserved in different food simulants and in the presence of competitive ions and in an environment comprising cysteine. In vitro biosafety assays on different cell lines showed no negative effect from the silica modification on the safety of the coatings.	(Strachowski et al., 2025)
The chitosan, nanopackaging, and modified atmosphere packaging effect on physical, chemical, and mechanical properties of button mushroom during storage	The use of nanofilm (due to the low permeability to oxygen and carbon dioxide), as well as the modification of atmosphere had a positive effect on the control of mushroom respiration rate and the improvement in its physical, chemical, and mechanical properties.	(Gholami et al., 2020)
Shelf life extension of white mushrooms (Agaricus bisporus) by low temperatures conditioning, modified atmosphere, and nanocomposite packaging material	Mushrooms packaged under the MAP behaved decidedly better after a prolonged storage time of 22 days at 4 °C. The test material had a positive impact on weight loss, cap opening percentage, and firmness of mushrooms compared with the control film	(Gholami et al., 2017)
Application of silver nanodots for potential use in antimicrobial packaging applications	The developed silver nanodot surfaces exhibited good antimicrobial activity against Gram-positive and Gram-negative bacteria and potentially can be used in antimicrobial packaging applications.	(Azlin-Hasim, Cruz-Romero, Ghoshal, et al., 2015)
Combination of antimicrobial silver low-density polyethylene nanocomposite films and modified atmosphere packaging on the shelf life of chicken breast fillets	The results have indicated that LDPE nanocomposite films containing Ag NPs could potentially be used as antimicrobial packaging for food applications.	(Azlin-Hasim, Cruz-Romero, Morris, et al., 2015)
LLDPE-based food packaging incorporated with nanoclays grafted with bioactive compounds to extend the shelf life of some meat products	In conclusion, it might be suggested that active clay nanocomposite packaging films could be used to extend the shelf life of fresh and/or processed meats.	(Tornuk et al., 2015)
Polyethylene with nano-powder (nano-Ag, kaolin, anatase TiO2, rutile TiO2).	The nano-packing material had a quite beneficial effect on physicochemical and sensory quality compared with normal packing material. Therefore, the nano-packing could be applied for preservation of Chinese jujube to expand its shelf life and improve preservation quality.	(Li et al., 2009)
Effect of chitosan/nano-silica coating on the physicochemical characteristics of longan fruit	The chitosan/nano-silica coating might provide an attractive alternative to improve the preservation quality of fresh longan fruits during extended storage.	(Shi et al., 2013)

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