Role of active packaging in the food industry: R~~ar~~eview Values of Nanotechnology

ABSTRACT:

In response to shifting consumer demands, food packaging's conventional function is continuing to change. Consumer desire for healthier, safer, and good quality meals with longer shelf-life is one of the current causes that are challenging the food packaging sector to produce new and better technology packaging solutions. Therefore, Active packaging (AP) can be used to satisfy these requirements. The biggest advantage of Active packaging (AP) is less food waste because the items have a longer shelf life. Undoubtedly, active packaging is a great option for a variety of food sector applications.In the upcoming years, the commercial success of active packaging systems should be anticipated as they represent the growth of food packaging in the future. In this review, a summary of active packaging technologies, including oxygen scavenger, moisture scavenger, ethylene absorber, antioxidant-releaser, CO_2 emitter, and antimicrobial packaging systems are provided.In particular, reviews of scientific studies emphasizing the advantages of these technologies for certain food products are conducted.However, the development of food nano-packaging is still in its early stage,despite~~of~~ having numerous opportunities to enhance packaging materials and functions.Although, due to the advancements in nanotechnology there might be higher chancesof enabling the creation of better active packaging.This article also discusses current breakthroughs in food ~~nanopackaging~~ nano packagingbased on active nanoparticles.

KEYWORDS: Oxygen scavengers, ethylene scavengers, antimicrobial, nanomaterial

INTRODUCTION~~:~~

Packaging is a crucial component of the food supply chain. The main purpose of food packaging is to increase the shelf life of packaged food materials by inhibiting adverse variations brought on by chemical impurities, temperature changes, microbial spoilage, moisture, O_2, external force, and light as well as to maintain the safety and quality of food items from the stage of manufacturing to the end of consumption[1].The noticeable shifts in customer demand and ~~behaviour~~ behaviorthat are likely to have an impact on the way we ~~utilise~~utilizeas well asanticipate~~from~~ packaging in the upcoming yearsare driving innovations in packaging[2].

Nanotechnology is the fabrication, modification, and ~~characterisation~~ characterizationof items, structures, or materials with at least one dimension and a length of 1–100 nm. Additionally, nanotechnology has sparked a new technological growth by enabling a vast scope of opportunities or the creation and application of systems, materials, and structures with novel orbetter quality in ~~a number of~~several sectors, including food, agriculture, medicine, and others[3]. In order to increase shelf life, it is also possible to construct nano food packaging to release enzymes, antioxidants, antimicrobials as well as nutraceuticals.Food nanostructured ingredients and food nanosensingare the two main applications of nanotechnology in the food business[4]. The subject of food nanosensing improves the safety and quality of food, but nanostructured food ingredients havea broad spectrum like food packaging and food processing(Figure 1). The biggest anticipated application of nanotechnology in the food business in the near future is novel food packaging technology, as recently described by Dasgupta and others (2015) regarding its usage in the agro-food industries, as one of the quickestdeveloping~~field~~fields in nano-research[5].

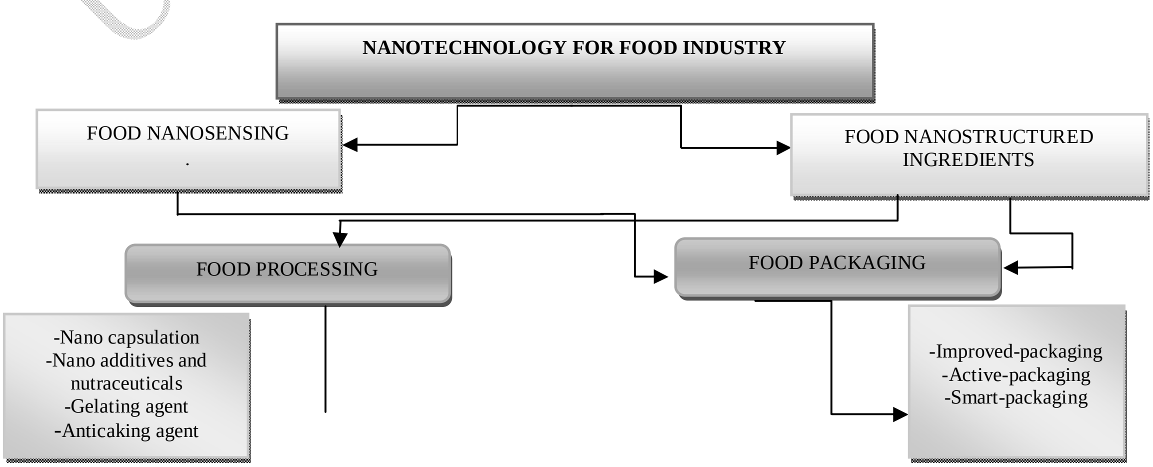

Figure 1. Use of nanotechnology in several food business sectors.

Several types of packaging materials ~~utilised~~utilizedin food industry including~~improved packaging~~improved packaging, ~~active packaging~~active packaging, and smart packaging. The main goal of this article, however, is to give a general summaryof active packaging systems which have recently been effectively used in food, ~~emphasising~~ emphasizingthe advantages for the specific food products. The current commercialization of food packaging containing nanomaterials will also be highlighted.

ACTIVE PACKAGING (AP)~~:~~

In AP systems, active substances like ethylene removers,water vapour absorbers, oxygen absorbers,preservatives, and others are purposefully added to packages to increase their protection function[6].Active packaging systems fall into~~two~~ ~~2~~groups: active-releasing systems (emitters)and active scavenging systems (absorbers). While the former eliminates undesirable components like odour, ethylene,CO_2, O_2,or moisture from the food or its environment, the latter adds substances like antimicrobials, CO_2, antioxidants, flavours, ethylene, or ethanol to the packaged food or into the headspace (Fig. 2).Nanocomposites (metal NP'slike copper, silver, and oxides like magnesium oxide and titanium dioxide), gas scavengers and antimicrobial film are the major components of active food packaging[7].

It extends the standard packaging's capabilities to offer protection, easyto use, prolonged shelf-life and storage period. It has been said that "packing of the future will not only be a barrier but it will also interact with packaged products"[8]. Expert predictions have also been stated that the future of food packaging lies with the newest generations of active packaging.

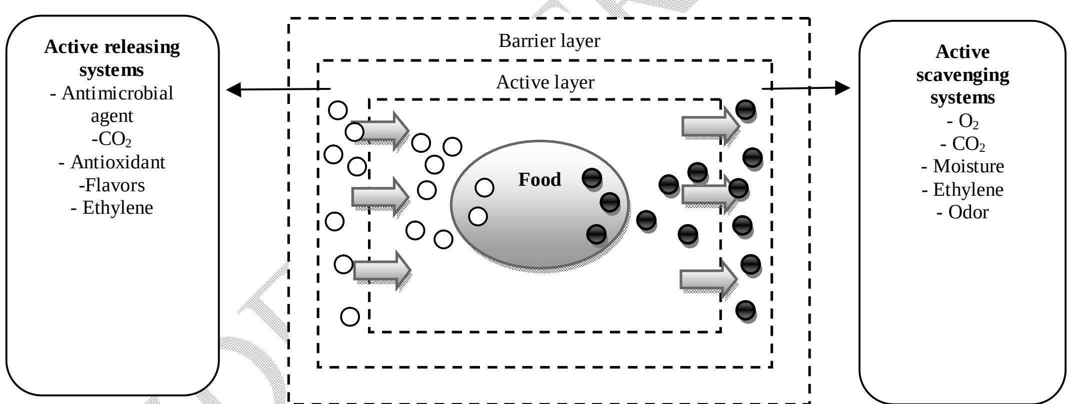

Figure 2. Active packaging systems

Active packaging, as opposed to conventional packaging materials, increases the shelf-life of ~~food~~food, and maintains its superior quality while~~interactiing~~interacting with the internal environment and the product[9]. As a result, active packaging solutions ought to be viewed as a novel approach to food packaging. They interact with the packaged item, alter its surroundings, and regulate its quality all at once.

ACTIVE PACKAGING TECHNOLOGIES~~:~~

1. **Oxygen scavenger (OS):** The growth of microorganisms including yeasts,aerobic bacteria, and ~~moulds~~molds,the existence of O_2 in food packaging hastens product degradation and the oxidation of lipid and ~~vitamin~~ vitaminsin food. It damages nutrients in food and causes ~~colour~~ colorchanges, disagreeable ~~flavours~~flavors, bad ~~odours~~odors, and unpleasant tastes[10].A high level of oxygen also reduces its shelf life.
   The O_2 in headspace gases reacts with perishable food into the package and speeds up the spoilage of various food products (~~such as~~e.g.~~spices,~~ spices, milk powder, sausages or meat), the breakdown of vitamins, and the rancidification of fatty foods, nuts, and oils as it encourages the growth of microbes. The remaining oxygen levels inside the package are actively reduced by oxygen scavengers.

The oxidative mode of action of the various types of OS could be either: (a) chemical, using cobalt[11], ferrousor iron salts[12], gallic acid, ascorbic acid,fatty acids orphotosensitive dyes, (b) biological (through the use of immobilized yeast on a solid material) or (c) biochemical (using enzymes)[13]. Iron is therefore the most prevalent kind of OS.

As per the following general theoretical equations, water activates iron-based OS, which then scavenge oxygen:

$$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3 \rightarrow 2Fe_2O_3 . 3H_2O$$
$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \rightarrow 2Fe_2O_3 . 3H_2O$$

Mu et al. (2014) and othershave developed a nano-Fe based oxygen scavenger (Table 1). Fe-NPs incorporated with and $CaCl_2$, NaCl and activated carbon and then filled into sachets[14].

Table 1: Oxygen-Scavenging Packaging Systems[13-18]

Active Substance	Package Material/Application	Benefit
Iron	In sachets HDPE and LLDPE films + modified kaolinite, NaCl and $CaCl_2$,activated carbon and Fe-NPs,	Inhibition of lipid oxidation
Iron-(II)-chloride and α-tocopherol	Nanoencapsulatedpolycaprolactone in fish gelatin film	Possibility of use in retortable pouches
Titanium dioxide	Placed on various polymer films Ethyl cellulose film	Possibility of packets that scavenge oxygen
Palladium, platinum	Nylon 6,6, PET, LDPE, PP	Regulate the transport of oxygen through active membrane components
Palladium	Deposited on poly (ethylene terephthalate) film	Potential use in ham and bakery products
TiO_2 or Alumina (Al_2O_3) and ascorbate enzyme systems	TiO_2-NPs, edible oils CaAsc/laccase, oleic acid, or Al_2O_3-NPs Coated or printed on PET films	Formulation of oxygen-scavenging ink for interior packaging surfaces

2. **Moisture scavengers:** The amount of moisture and the activity of the water in various types of meals are important elements impacting their quality and safety. According to Yildirim and others (2019), there are various types of moisture control strategies used in packaging, such as vacuum packaging, which involves removing the humid air from the headspace, moisture prevention (using barrier packaging), moisture reduction (by modified atmosphere packaging or MAP), which involves substituting the humid air in the headspace with dry MA gas, or and moisture elimination (by using a desiccant or absorber)[19].Table 2 contains some examples of food product applications; however, pads are eliminated because they are already widely utilized in the market.

Table 2–Moisture-Scavenging Packaging Systems[20-23]

Active Substances	Package Material/Application	Food Tested	Benefit
$CaCl_2$/ bentonite/ sorbitol	Powder in bags/trays in the package	Mushroom	Reduction in browning index (BI 14.8) compared to control (BI 18), better product appearance, and an increase in shelf-life from 1-5 days at 10 °C. Decreased moisture condensation inside the packaging.
Poly (acrylic acid) sodium salt	Powder in porous "tea bag" in sealed containers	Corn	DecreaseinDecrease in the presence of aflatoxin
Sodium chloride	Thermoformed multilayer trays: polyethylene /foamed hygroscopic ionomer-sodium chloride/polyethylene	Strawberries and tomatoes	Control of in-package RH below 97 percent for seven days at various temperatures Water loss at 5 °C decreased from 4.5 to 1.3 g
	Thermoformed multilayer trays: Polypropylene /foamed and stretched polypropylene– Sodium chloride/PE/ethylene vinyl alcohol	Mushroom	

3. **Ethylene absorber**:Climacteric respiration is the major metabolic process occurring in many fruits and vegetables after harvesting[24]. Thereby, ethylene, a natural plant hormone, accelerates respiration, leading to maturity, softening the product tissues ~~and,~~and therefore accelerating senescence. On the other side, its accumulation can cause the yellowing of green vegetables and may be responsible for a number of undesirable reactions, such as the development of bitter flavors and chlorophyll degradation.

The most common agent of ethylene removal is potassium permanganate[25], which oxidizes ethylene to acetate and ethanol. Due to its toxicity, however, potassium permanganate cannot be integrated into packaging material with food contact and is therefore usually applied in sachets[26]. Ethylene can also be removed by physical adsorption on active surfaces such as zeolite, clays, or activated carbon, which may be incorporated in packaging materials. Inorganic nanoparticles including metals such as palladium (Pd) or silver (Ag), and metal oxides, such as zinc oxide (ZnO) or titanium oxide (TiO2), have gained ~~interests~~ interestdue to their attractive physicochemical properties.The authors showed that the Palladium-promoted material efficiently scavenged ethylene that was either exogenously supplied or generated by avocado or banana (Table 3).

Table 3: Ethylene-Scavenging Packaging Systems[24,27-30]

Active Substances	Package Material/Application	Food Tested	Benefit
Palladium	Zeolite	Banana and avocado	Scavenged ethylene
ZnO	Coating a poly (vinyl chloride) film	Fresh cut apples	Showed a much lower rate of fruit deterioration
TiO_2	LDPE film	Strawberries	The ethylene produced by strawberries in the nano-TiO_2 LDPE-package was drastically reduced
Ag	Cellulose-hybrid material	Fresh cut melon	The senescence of the melon cuts was delayed, implying blockage of ethylene-mediated effects on the ripening, resulting in a lesser amount of ripe product.
Ag + Titanium dioxide	Polyethylene film (+kaolin)	Date, strawberries and bayberries	Browning with climate change were both severely hampered

4. **Antioxidant releaser:**The creation of packaging that releases antioxidants for food applications has picked up in recent years. To stop the oxidation of lipid, synthetic antioxidants likebutylatedhydroxyanisoleand butylated hydroxytoluene are frequently employed in food packaging.

On the other hand, due to potential negative effects on human health, customers today prefer to ~~utilise~~ utilizefoods devoid of any synthetic additives. Due to their biodegradability and safety, natural antioxidants would be a good replacement for synthetic antioxidants[31,32]. Today's research focuses on adding natural antioxidants to polymer- and biopolymer-based food films[33-36]. Natural antioxidants likeessential oils (EOs), plant extracts, tocopherols, and polyphenols, are becoming more and more popular for use in active packaging materials[37,38]. Table 4 summarises a few recent advancements in this area.

Table 4: Antioxidant- Releaser Packaging Systems[39-45]

Active Substances	Package Material/Application	Food Tested	Benefit
Butylated hydroxytoluene	LDPE film	Fresh fish	Less tissue damage, less lipid oxidation, less protein denaturation, and preserved firmness
BHA, BHT and α Tocopherol	PLGA film	Dry buttermilk powder and dry whole milk	An increase in oxidative stability
α Tocopherol	Multilayer film: LDPE/high-density polyethylene/ethylene vinyl alcohol low-density polyethylene film Poly (lactic acid) film	Whole milk powder Corn oil Soyabean oil	An increase in oxidative stability
Green tea extract	Chitosan film	Pork sausage	Improvement of color and oxidative stability
Acerola and mango pulp	Cassava starch film	Palm oil	An increase in oxidative stability

5. **Carbon dioxide emitter:**CO_2 positively affects the preservation of food's initial freshness and prevents the development of odor-related deterioration[46]. CO_2 is widely used in the food sector for quality preservation and increased shelf-life due to its beneficial antibacterial qualities.

For poultry, fish, fresh meat, and non-climacteric fruits, high CO_2 concentrations would typically be chosen to successfully inhibit the growth of microorganisms, which lengthens the lag phase and time during the logarithmic microorganism's phase through a complicated array of methods[47].By incorporating CO_2 emitters into modified atmosphere packaging, it may be possible to boost fill levels, reduce package sizes, increase transport effectiveness, and reduce environmental impact overall. In addition to preventing packaging deformation, the release of $CO_2$from a tailored emitter system can offset the initial storage-related CO_2 absorption into the food product.

The active chemicals inside the absorbent pad react when liquid is caught that is leaking out of the product, creating CO_2. When the absorbent pad catches liquid that is leaking out of the product, the active chemicals inside react, releasing CO_2.Table 5 summarises the carbon dioxide releaser techniques that are now present for preserving ~~the~~ food, along with their uses and advantages for various food products.

Table 5: Carbon dioxide emitters in packaging systems[46, 48-50]

Packaging Method with Emitter	Food tested	Quality Parameters	Benefit
Modified atmosphere packaging (60% carbon dioxide, 40% nitrogen) and vacuum	Cod	Drip loss, microbial assay, sensory analysis	Extension of sensory and microbiological shelf-life and improvement of initial freshness
MAP (60% CO_2, 40% N_2)	Reindeer meat	Cooking loss, antioxidant capacity, drip loss, pH, sensory analysis, microbial analysis	Reduced drip loss (3.0 wt% in MAP packages without a carbon dioxide emitter, 1.0 wt% in MAP with a carbon dioxide emitter), and decreased growth of bacteria
MAP (100% CO_2)	Chicken	Drip loss, microbial assay, pH	Increased sensory and microbiological shelf-life; 100% CO_2 packing made easier; less drip loss; CO_2 emitter
Modified atmosphere packaging (60% CO_2, 40% O_2)	Cod	pH, sensory analysis, drip loss, microbial assay	At a reduced g/p ratio, sensory and microbiological shelf-life are maintained.

6. **Antimicrobial packaging systems:** The primary goal of antimicrobial packaging is to preserve and increase the shelf-life of the food item by prohibiting ~~themicroorganism's~~microorganismgrowth.This could be achieved by incorporating an active substance inside the packing material or by adding a coating layer there[51].Antimicrobial agents behave variably depending on the pathogenic bacteria because of different physiologies.There are two ways that an antimicrobial agent works: either by blocking a microorganism's vital metabolic processes (~~lactoferin~~lactoferrinandethylenediaminetetraacetic acidact as coupling agents of charged polymers), or by destroying the membrane structure or cell wall.Figure 3 displays several antibacterial substances that could be used ~~into~~ infood packaging methods.

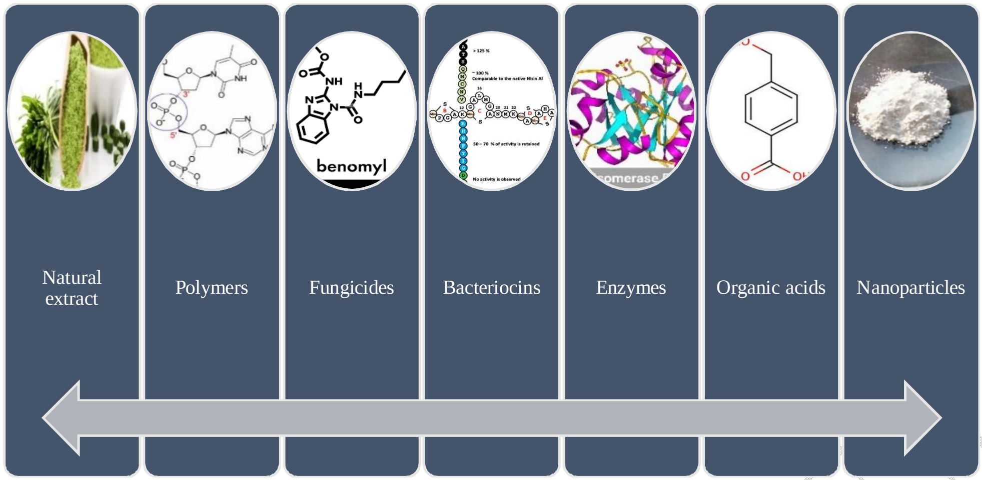

Figure 3. Various antimicrobial substances for antimicrobial active packaging systems

Nanomaterials containing Ag, TiO_2, and ZnO NP's have a good antimicrobial activity which is a very suitable agent for antimicrobial AP systems[52]. Food packaging frequently uses TiO_2 nanoparticles, which are not toxic to humans as well as authorized as food additives and food contact materials[53].

However, the stabilization of essential oils during processing, enhancement of their physicochemical qualities, and enhancement of their health-promoting benefits are all possible by using nanoencapsulation techniques.Herbs and spices offer potentially extremely useful sources of biodegradable, renewable compounds like polyphenols, which have strong antibacterial and antioxidant effects.They are therefore suitable materials to include in active food packaging[54].Because of the prevention of microbial growth in various food products, essential oil-loaded biopolymeric nanocarriers in particular exhibit promising antibacterial and antioxidant activity and are ~~an~~ appropriate material for active food packaging[55].

Allyl isothiocyanate, natamycin,chlorine dioxide, glucose oxidase, triclosan, silver zeolite, and silver are also often utilized as active components in commercially available antimicrobial AP systems[56]. In a very recent study, researchersincreased the shelf life of fresh chicken held at 4°C by several polyethylene films containing TiO_2 andAg nanoparticles and created as potential active packaging films. The findings showed that the most effective antimicrobial film for both gram-negative bacteria(*E. coli*)and gram-positive (*S. aureus*) was one that contained 5% Ag and 5% TiO_2 nanoparticles[57]. Ag nanoparticles and Accasellowiana extracts functionalized into nanocomposite poly (ethylene oxide) films also showed antibacterial activity against *E. coli* and *S. aureus*[58].Antimicrobial nanoparticles are examined independently because the nanosize boosts or permits antimicrobial action (Table 6).

Table 6–Antimicrobial food packaging systems[59-64]

Active substances	Package Material/Application	Microorganisms tested	Food tested	Benefit
Silver/titanium dioxide	LLDPE/Low-density polyethylene	*A. flavus*	Cooked rice	Decrease of *A. flavus* by ten times
Ag	Polyethylene	*B. cereus, B. subtilis*,moldsyeasts	Bread	Increased shelf life byup to six days
Silver/Zinc oxide	Low-density polyethylene	*L. monocytogenes, P. aeruginosa and E. coli*	Chicken breast fillets	Reduction in the growth of bacteria (destruction of 99.99% of inoculated microorganisms)
Zinc oxide	Active films (based on glycerol, $CaCl_2$ and sodium alginate)	*S. aureus, S. typhimurium,*	Poultry meat	Initial bacterial count decline
TiO_2	LDPE	*R. mucilaginosa*	Fresh pears	Reduction of more than 2 log CFU/g in mesophilic bacteria and yeasts
Copper	Polylactic acid	Pseudomonas spp. isolated from spoiled fiordilatte cheese	Fiordilatte cheese	Extended shelf life of up to 9 days

CONCLUSION:

Many studies have been conducted in recent years on the development of novel active packaging technologies, resulting in a diverse range of AP systems ~~which~~ thatcould be utilized to increase the shelf-life of food ~~product~~products. This study highlights the huge scope of AP systems as well as~~comes to the conclusion~~concludes that all active packaging technology categories examined have similar implementation challenges when applied to practical food applications. Additionally, it is evident from all the research done over the past 10 years that nanotechnology presents a lot of potential for innovative advancements in food packaging that will benefit both consumers and ~~business~~businesses. Even at this early level, the use of nanotechnology has shown significant benefits in enhancing the characteristics of packaging materials, and it will continue to need expenditures to finance research as well asadvancements ~~in order to~~to comprehend the benefits and drawbacks of involving nanotechnology in AP packaging systems. The application of nanotechnology in the fabrication of food packaging can ~~offers~~ offerseveral advantages in ~~term~~termsof increased functional qualities. Numerous nanomaterials have been evaluated*in vitro* towards microbes, particularly those used in antimicrobial packaging solutions. However, food tests are very essential since the ingredients in food may have an impact on the action of the active substances. The efficient and effective deployment of active nanoparticles in food packaging requires broad consumer acceptance and legislative support, as well as a cost that is consistent with the value ~~realised~~ realizedby the particular food product.

NOMENCLATURE:

AP: active packaging
BHA: butylatedhydroxyanisole
BHT: butylated hydroxytoluene
EDTA: ethylenediaminetetraacetic acid
EVOH: ethylene vinyl alcohol
HDPE: high-density polyethylene
LDPE: low-density polyethylene
LLDPE: linear low-density polyethylene
NP's: nanoparticles
MA: modified atmosphere
MAP: modified atmosphere packaging
OS: oxygen scavenger
PCL: polycaprolactone
PE: polyethylene
PET: poly (ethylene terephthalate)
PLA: polylactic acid
PLGA: poly(lactide-co-~~glycolic)acid~~glycolic) acid
PP: polypropylene
PVC: poly (vinyl chloride)

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