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REVIEW

A Relook at Food Packaging for Cost Effective by Incorporation of Novel Technologies

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Abstract Food packaging is one of the essential subject areas in food technology that play an important role in preserving all types of foods. Due to many disadvantages like a non-biodegradable and environmental problem in food packaging industry, a newer concept of use of biodegradable materials in food packaging from botanicals created tremendous innovative ideas in food packaging from past few years. An increased interest in hygiene in everyday life as well as in food, feed, and medical issues lead to a strong interest in films and blends to prevent the growth and accumulation of harmful bacteria. A growing trend is to use synthetic and natural antimicrobial polymers, to provide non-migratory and non-depleting protection agents for application in films, coatings, and packaging. The aim of this review was to offer a complete view of the state of the art on natural biodegradable polymer packages for food application compared to synthetics. Also, heightened overall developments in botanicals, natural and synthetic biopolymers in food packaging and its applications were described by focusing future improvements. This is a timely review as there has been a recent renewed interest in research studies, both in the industry and academia, towards the development of a new generation of biopolymer-based food packaging materials with possible applications in other areas. A lot of achievements in nanotechnology compared to synthetic materials attracted food industry for its wonderful applications in packaging was highlighted.

Keywords Packaging · Biodegradable · Nano-particle · Botanicals

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Introduction

The best intention of recent research on botanicals started to develop alternative strategies to reduce dependency on synthetic chemicals. Plants have potential to synthesize a vast number of secondary metabolites, like phenols, phenolic acids, flavones, flavonols, flavonoids, quinones, tannins, and coumarins. The components with phenolic structures like carvacrol, eugenol, and thymol, had been extremely active against to pathogen. These group of compounds show antimicrobial outcomes and serves as defense mechanisms against pathogenic microorganisms.

In the food industry, antimicrobial substances are used in the form of sprays or dips. But, such direct application has limited benefits because the active substance is neutralized on contact with the food or it may diffuse rapidly from the surface into the food. Whereas, immobilization of such substances to the surface of a polymer helps to anchor them to the material thereby preventing their movement

Table 1 Antimicrobials incorporated directly into polymers used for food packaging

S. no.	Packaging Technology	Active molecule used	Against Pathogens	References
1	Multilayer antimicrobial packaging	Benzoic acid, Sodium metabisulphite, Tert-butylhydroquinone Etil-*N*-lauroyl-L-arginine Cinnamon essential oil and Oregano essential oil	*Fusarium oxysporium* *Mucor mucedo* *Penicillium expansum* *Escherichia coli O157:H7* *Saccharomyces cerevisiae*	[33]
2	Bio-nanocomposite film	Chitosan carboxymethyl cellulose zinc oxide	*Staphylococcus aureus* *Pseudomonas aeruginosa* *Bacillus cereus* *Listeria monocytogenes* *Escherichia coli O175: H7* *Aspergillus niger* and *candidia albicans*	[98]
3	Chitosan film incorporated with thinned young apple polyphenols (YAP)	Young apple polyphenols (YAP) Chitosan	*Escherichia coli*, *Listeria monocytogenes a Staphylococcus aureus* *Colletotrichum fructicola*, *Botryosphaerial dothidea Alternaria tenuissima* *Saccharomyces cerevisiae*, *Baker's yeast* and Tropical candida	[87]
4	Chitosan-TiO2 Composite Film	TiO2 nano-powder Chitosan	*E. coli*	[99]
5	Antimicrobial loaded films	Chitosan Ciprofloxacin Silver nanoparticles	*P. aeruginosa*	[6]
6	Novel green nano composites films fabricated by indigenously synthesized graphene oxide and chitosan	Graphene oxide and Chitosan		[42]
7	Several phenol compounds: acids, essential oils components and dopamine.	carvacrol in high-density polyethylene for active packaging	*Staphylococcus aureus and Escherichia coli*	[65]
8	Flexible films of polypropylene (PP) and polyethylene/ethylene vinyl alcohol copolymer (PE/EVOH)	Cinnamon (*Cinnamomum zeylanicum*), oregano (*Origanum vulgare*), clove (*Syzygium aromaticum*), or cinnamon fortified	*Escherichia coli*, *Yersinia enterocolitica*, *Pseudomonas aeruginosa*, *Salmonella choleraesuis*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, and *Enterococcus faecalis*; *Penicillium islandicum*, *Penicillium roqueforti*, *Penicillium nalgiovense*, *Eurotium repens*, and *Aspergillus flavus* and *Candida albicans*	[49]
9	Low-density polyethylene (LDPE)	Essentials oils of oregano (*Origanum vulgare*) and thyme (*Thymus vulgaris*)	*Salmonella typhimurium*, *Listeria monocytogenes*, and *Escherichia coli O157:H7*	[32]
10	Zein films as flexible bioactive packaging	Phenolic acids -Gallic acid, p-hydroxy benzoic acid ferulic acids or flavonoids (catechin, flavone or quercetin)	*Listeria monocytogenes and Campylobacter jejuni*	[7]
11	A corona treated LDPE film	Incorporation of essential oils (EOs) of oregano and thyme	*Listeria monocytogenes*, *Salmonella typhimurium, and E. coli O157:H7*	[92]
12	Whey protein based film	1% oregano, 1% pimento or 1% oregano-pimento (Eos)	*E. coli O157:H7 and pseudomonas spp*	[61]
13	Chitosan edible films	Garlic oil	*E. coli*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, *and Salmonella thyphimurium*	[69]

Table 1 continued

S. no.	Packaging Technology	Active molecule used	Against Pathogens	References
14	Low-density polyethylene (LDPE) package	1% of grape fruit seed extract (GFSE)	*Aerobic bacteria and yeasts*	[45]
15	Multilayer PE films	0.5% and 1% of grapefruit seed extract (GFSE)	Escherichia coli *IFO 3301*, Staphylococcus aureus *IFO 3060 and* Bacillus subtilis*IFO 12113*	[36]
16	Low-density polyethylene (LDPE) package	1% Rheum palmatum and Coptis chinensis extracts	Reduced the growth of total viable count, lactic acid bacteria, and yeasts on fresh strawberries	[20, 21]
17	Low-density polyethylene (LDPE) film	5% Propolis extract, chitosan biopolymer, or clove extract	Lactobacillus plantarum and Fusarium oxysporum	[5]
18	Linear low-density polyethylene (LLDPE) film	0.05% linalool or methyl carvacrol	*E. coli*	[88]
19	Edible packaging films	1–4% of whey protein isolate incorporating oregano, rosemary, and garlic EOs	*E. coli O157:H7*, *L. monocytogenes*, *Staphylococcus. aureus*, *Salmonella enteriditis*, *and Lactobacillus plantarum*	[85]
20	Alginate–apple puree edible film (AAPEF)	oregano oil/carvacrol; cinnamon oil/cinnamaldehyde; and lemongrass oil/citral	*Escherichia coli* O157:H7	[74]
21	Edible packaging films	1% of different oleoresins (olive, rosemary, onion, capsicum, cranberry, garlic, oreganim, and a mixture of oreganum plus carvacrol) into chitosan, carboxymethyl cellulose	*L. monocytogenes and natural microflora*	[68]
22	Milk protein-based edible films	1% oregano, pimento, and a 1:1 ratio of oregano-pimento	*E. coli O157:H7 and Pseudomonas spp*	[61]
23	Antimicrobial packaging	Chitosonium acetate	*Listeria monocytogenes*, *Salmonella* spp. and *Staphylococcus aureus*	[30]
24	Ethylene copolymer films	Chitosan	*E. coli and Listeria monocytogenes*	[41]
25	Chitosan-hydroxy propyl methyl cellulose (HPMC) films	1% chitosan, 0.5% chitosan-1.5% HPMC, 1% chitosan-1.5% HPMC, and 1.5% chitosan-1.5%	*Listeria monocytogenes*	[59]

into the food and hence, sustaining their activity and stability over a long period of time. Covalent immobilization of an enzyme prevents its aggregation, proteolysis, and interaction with the hydrophobic surface. Currently, there is a strong interest in the use of renewable and non-toxic supports for immobilization to make the process more eco-friendly [53].

Packaging is one of the most important methods to maintain the quality of food products for storage, transportation, and end use. Oxygen, light, water vapor, bacteria and other contaminants can affect the product without protective packaging after processing [1]. It prevents the quality deterioration and facilitates distribution and marketing. Suitable packaging can slow down the deterioration rate and hence extend the shelf life of food. Use of petroleum-derived polymers such as polyethylene, polystyrene, polypropylene etc., are dominating in the packaging field, but these materials are not environmental friendly. Nowadays people are more conscious about the environment and they move towards environmental eco-friendly packaging systems.

Silver and gold nanoparticles show antibacterial activity. Generally, they are prepared by chemical and biological methods. Chemical preparations are widely studied because of their ease and wide applications. Several nano-composites have been reported by using various nanoparticles and with synthetic polymers [22]. Silver, gold, and copper nanoparticles are reported to exhibit a strong biocidal effect on more than sixteen species of bacteria including *Escherichia coli* [50]. Metallic, ceramic and, metal nanoparticles are added to polymers to obtain unique physical and mechanical properties which cannot be achieved by adding micron-sized particles. The extent of modification of the property depends on the base polymer, the size, distribution, and dispersion of the nanoparticles and on the adhesion at the filler-matrix interface [89]. A nano-particle dispersed in the polymer is called polymer nano-composite and it is considered as a single homogeneous material. These materials exhibit unique thermal, mechanical, and biological properties when compared to conventional composites. Nanoparticles have an extremely large relative surface area to volume, and hence increasing their contact with bacteria or fungi, vastly improve their bactericidal and fungicidal effectiveness. They bind to microbial DNA, preventing bacterial replication, and to sulfhydryl groups in the metabolic enzymes of the bacterial electron transport chain, causing their inactivation [82]. Pertaining to current literature available information here we tried to relook for the natural sources, and technology. For public safety purpose, we took present investigation and pointed out the solutions of food safety.

Now Again in the Twenty-first Century, Why We Should Consider Botanicals?

Scientists are moving back to botanicals due to following reasons:

- Eco-friendly.
- Organic forming.
- Easily bio-degradable.
- Integrated diseases management.
- Sustainable solutions in agriculture.
- Less toxicity and use it as it is in food.
- Use in multiple applied technology based applications.

Recently in 2016 Indian government has banned almost 344 drugs quoting the exact phrase “These antibiotic drugs containing fix dose of one or more combination of antibiotic drugs from bacteria mainly containing atropine and analgesic or antipyretic are causing anti-microbial resistance. The usage could even result in organ-failure”. Many of these antibiotic and synthetic drugs have already been banned in many countries or cannot be sell without Federal approval. Plants secrete number of secondary metabolites having aromatic structures as a by-product of the usual metabolic processes. Until 2016, almost 50,000 secondary metabolites have been discovered in the plant system, involved in plant defense system against Bacteria, Viruses, and Fungi etc. Many of these possess antimicrobial activity against many classes of bacteria, virus, insects and many other harmful organisms [38]. In 2011, Indian medicinal plants have been detected with potential activity against HIV [80]. So, Botanicals show promising future towards treating some of fatal diseases in the world and list of antimicrobials incorporated directly into polymers used for food packaging tabulated in Table 1.

There are six major phytochemical groups commonly found in botanicals are phenolic and phenolic acids-chlorogenic acid, protocatechuic acid, ferulic acid, caffeic acid, flavonoids and iso-flavonoids, saponins, steroids, tannins, and coumarins and pyrones. These major phytochemical mechanisms of action were described in Table 2 [23, 54].

Why Botanicals are Losing it Attention?

- Less effective.
- Rapid degradation.
- Less availability of formulations.
- Extraction methods are not properly standardized.
- Need proper knowledge on formulations for bioavailability.
- Most studies are in vitro efficacy, not effective at in vivo level.

Table 2 Common major plant phytochemicals present in botanical sources

Class	Sub-class	Mechanism of action
Phenolics	Simple phenols	Membrane disruption, substrate deprivation
Phenolic acids	Phenolic acids	Bind to adhesins, complex with cell wall, inactivate enzymes
Terpenoids, essential oils		Membrane disruption
Alkaloids		Intercalate into cell wall
Tannins		Bind to proteins, enzyme inhibition, substrate deprivation
Flavonoids		Bind to adhesins, complex with cell wall, Inactivate enzymes
Coumarins		Interaction with eucaryotic DNA
Lectins and polypeptides		Form disulfide bridges

- Some chemical components shows side effect to human and plants.
- Poor knowledge on proper extraction and determination, and validation of potent compound.

Packaging helps to protect the food spoilage from different microorganisms, physically damage, filth, and insects. Active packaging is the incorporation of novel nonmaterial's into the packing material to prolong the shelf-life of the product while retaining dietary satisfactory and assuring microbial safety [43]. Nowadays a number of different methods available for better management of food spoilage. But the new era deviating from synthetic to natural things to avoid the possible dangerous effects of chemicals on the health.

Foods are primarily packaged to protect them from the environment with good biophysical properties to the packaging material (Table 3) and to provide ingredient and nutritional information to the consumers. However, food packaging has become a central focus of waste reduction efforts because proper waste management is important to protect human health and environment. The use of plastics over glass and metals has continued to increase due to their good materials properties and low cost. Thus, they find their origin in the petrochemical industry making them non-biodegradable and non-renewable. With the current focus on exploring alternatives to petroleum and emphasis on reduced environmental impact, research is increasingly being directed at the development of biodegradable food packaging from renewable resources.

Synthetic polymer material has been extensively used in every field of human life, most of which are derived from petroleum and its derivatives; the most common of such material is non-biodegradable [64]. The petro-based polymers used widely for food packaging are polyethylene terephthalate (PET), polyethylene (PE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). Such materials have high mechanical support, high-speed production and low permeability and low production costs as well. The huge amount of waste generated by usage of non-biodegradable materials are hazardous to environment, difficult to eliminate [10] and many other issues associated with food packaging materials (Table 4). The material which is biodegradable are therefore attention since 1970's [64]; especially in context to medical usage (suture materials), food industry (spoilage resistant packaging materials) etc. Although biodegradable material such as polycaprolactone (PCL) are available from petroleum sources, still developing food packaging materials with well defined properties (Table 5) from natural sources for different applications has been a hot topic for several years due to rise in prices of highly limited artificial sources such as petroleum [28, 44]. It's important to satisfy the consumers demanding of more environmentally friendly packaging i.e. natural products, bio-based films or Biopolymers. This notion will continue to be highly relevant with respect to consumables (in the food industry) [24, 81].

Synthetics

Synthetic drugs are chemical synthesized imitating natural antimicrobial substances. Gerhard Domagk in 1932 discovered the red diazo dye, Prontosil having antibacterial activity and low toxicity (mice). It is considered as a first synthetic drug for which he was awarded Nobel Prize in 1939. Prontosil was a derivative form of Sulphonamide which was realized later on. Sulphonamides, Cotrimoxazole, Quinolones are some of the basic synthetic drugs which are used for medicinal purposes from several decades. Numerous synthetic chemicals are also used as preservatives in food and pharma industries.

Mode of Action of These Synthetic Drugs are Classified on the Basis of Their Activity

Anti-Metabolites

Most of the time synthetic drugs act as a competitive inhibitor of metabolites and halt basic life process in

Table 3 Biophysical properties of packaging material

Material	Characteristics	Advantages	Disadvantages	Cost
Glass	Food compatibility	Inert, impermeable to moisture and gases, thermally stable	Brittle and breakable	Is low cost to produce but expensive to transport
	Consumer issues	Transparent (easy to see through), can be colored for light sensitive food products	Fragile and heavy to transport and Relatively difficult to decorate	
	Environmental issues	Reusable and can be recycled	–	
Aluminum	Food compatibility	Non-corrosive, impermeable to moisture and gases, thermally stable	Structural strength is limited and cannot be welded	It's costly, but can be recycled repeatedly
	Consumer issues	Potable, lightweight, non-breakable, easy to decorate	Can be casted into limited shapes	
	Environmental issues	Economic to recycle	Difficult to separate when laminated	
Tinplate	Food compatibility	Strong, thermally stable, with stands corrosion	Reactive with food	It's cheaper than aluminum
	Consumer issues	Easy to decorate	Limited accessibility; requires can opener	
	Environmental issues	Recyclable and easy to separate (magnetic)	Heavier	
Tin-free steel	Food compatibility	Moldable, Strong, thermally stable, corrosion resistant	Corrosive, requires molding	It's cheaper than Tin-plate
	Consumer issues	Easy to decorate	Limited accessibility; requires can opener	
	Environmental issues	Recyclable and easy to separate (magnetic)	Heavier	
Polyolefins	Food compatibility	Excellent barrier to moisture, strong, chemical resistant	–	Low cost
	Consumer issues	Light	–	
	Environmental issues	High energy source by incretion	Recyclable only in semi-flexible form; difficult to identify and separate when in film-form	
Polyesters	Food compatibility	Heat can be sealed, hot filing can be put	–	Cheap, but relatively expensive amongst plastic
	Consumer issues	Excellent barrier to moisture, Shatter proof and clarity	–	
	Environmental issues	Recyclable	Recyclable in rigid form; difficult to identify and separate when in film-form	
Polyvinyl chloride	Food compatibility	Moldable, chemical resistant	–	Low cost
	Consumer issues	High clarity	–	
	Environmental issues	Recyclable	Needs to be separated from other material; contains chlorine.	
Polyvinylidene chloride	Food compatibility	High barrier to both gases and moisture, resistant to chemicals	–	Cheap, but relatively expensive amongst plastic
	Consumer issues	Prevents product quality from deteriorating	–	
	Environmental issues	Recyclable	Needs to be separated from other material; contains chlorine.	
Polystyrene	Food compatibility	Found as rigid film or foam-form	Poor barrier	Inexpensive
	Consumer issues	Reasonable rigidity	–	
	Environmental issues	Recyclable	Needs to be separated from other material	

Table 3 continued

Material	Characteristics	Advantages	Disadvantages	Cost
Polyamide	Food compatibility	Good barrier and reasonably strong	–	Low cost
	Consumer issues	–	–	
	Environmental issues	Recyclable	Needs to be separated from other material	
Polylactide (PLA)	Food compatibility	Can be hydrolyzed i.e. biodegradable	–	Relatively costly
	Consumer issues	–	–	
	Environmental issues	Recyclable	Needs to be separated from other material	
Paperboard	Food compatibility	Good ratio of strength and weight	Poor light barrier	Low cost
	Consumer issues	Low density, easy to decorate, low cost of production, efficient production	Loses strength with moisture and tears easily	
	Environmental issues	Recyclable, made from sources that are renewable	–	

Bacteria or fungus. Sulfa drugs compete with p-aminobenzoic acid (PABA), play important role in biosynthesis of Folic acid. Folic acid plays a crucial role as co-factor of many enzymes. Sulphanilamide acts as a structure analog of PABA. Anti-metabolites also act by uncoupling the reactions. Bronopol and organo-mercurials target thiol group containing enzymes present in the cytoplasm.

Cell Membrane Agents

A compound like parabens, hexochlorophene, dichlorphene (phenols) disturbs membrane permeability of the cell turning it into "leaky" and ultimately leads to cell death due to loss of cytoplasm containing essential constituent [29, 39]. Sorbic acid interferes with transport of molecules across the cell membrane and affects fumaric acid oxidation. Chelators such as EDTA form complex with diatomic ions such as Ca2+ and Mg2 [76]. Hence, they disturb the integrity of membrane and strengthen the effect of other antimicrobial agents like 4-chloroxylenol.

Cell Wall Agents

A compound like Glutaraldehyde, phenols, EDTA involve in cell wall lysis. Glutaraldehyde irreversibly crosses- link with cell-wall. Although, the synthetic drugs have proved efficient in treating many diseases and avoiding spoilage but, these chemicals have many adverse effects which overshadow their treatment efficiency. Drugs like fluoroquinolones, *Co*-trimoxazole, Sulfa drugs have side effects like Nausea, Vomiting, Dizziness, Headache, Mental depression, Confusion, Bone marrow depression, Loss of appetite, Colic, Drowsiness, and Unconsciousness.

In November 2015, FDA advisory committee handed a report accounting risk factors associated with Fluoroquinolone antibacterial drug in acute bacterial sinusitis, Bronchitis, and urinary tract infection. In the report, a committee has mentioned various side effects like Neuropathy, Cardiac Arrhythmia, Tendonitis, and Tendon rupture. So, a committee has recommended label warnings because of rare but detrimental effects [17]. In the case of preservatives also there are following adverse effect:

- *Sulphites* According to FDA, different form of sulphite preservative causes allergies in more than million people and these allergies include Asthma, Headache, and Anaphylactic shocks.
- *Sodium benzoate, benzoic acid* Sodium Benzoate can react with Vitamin C and form Benzene which act as a Carcinogen causing Leukaemia and other Cancer.
- *Propyl gallate*—People consuming propyl gallate containing food are more prone to cancer.

Table 4 Issues associated with packaging material

Type of contamination	Food safety problem	Issues
Microbial	Integrity loss	Breakage in seals, leakage, packaging finish allows entry of contaminants
	Anaerobic conditions/Low oxygen levels	Low oxygen resultant of microbial respiration, leading to tox information in product
Chemical	Migration	Packaging constituents migrate to food products inside
	Environmental contaminants	Toxicants in environment like diesel exhaust may penetrate films
	Recycled packaging	Post-contaminants may get carried to new package while recycling of films
Insect	Post packaging contaminants	Insects may enter commonly used food packaging
Miscellaneous	Injuries to package	Pressurized containers may explode, broken cans, boxes; cuts or lacerations
	Inappropriate processing	Under processed food and/or insufficient sterilization causing food poisoning
	Loss in quality	Aroma or nutrients or both may be absorbed by packaging materials; false odors
	Foreign objects	Glass shards or metal pieces in product

- *BHA, BHT, and TBHQ* These chemicals after prolong intake can act as carcinogen.
- *Sodium nitrite and nitrate* At higher temperature, they form Nitrosamine, which is a Carcinogen.

Synthetic preservative and chemicals has various side effects which range from very mild to life-threatening. So, it is best to use botanicals as an alternative substitute which has very less or no side effect and cost effective too. Botanicals such as *Salvia officinalis*, *Cinnamomum* Sp., *Rosmarinus officinalis*, *Pimentaracemosa*, *Syzygiumaromaticum*, *Citrussps.*(citral) essential oils can be used as a substitute of synthetic preservatives [97]. Synthetic and natural polymers characteristic features were depicted in Table 6. Researchers so far proved that botanicals have great potential as preservatives and medicinal substitute avoiding antimicrobial resistance and side effects.

Nature Versus Man

Many food-borne diseases (referred as food poisoning or food-borne illness) result from the consumption of soiled or contaminated food by pathogenic bacteria, fungi, viruses, and parasites. The economic burden associated with these can affect food companies, peoples, and reputation of the country. Still, diseases associated with these pathogens globally still not under the control, which intern leading to great economic imbalance and mortality rate. May be primary cause associated with handling food in the unhygienic state, practices during food production, transport and storing conditions. So there is a need for many novel, cost effective, applicable steps to combat future outbreaks. Individual pathogens develop their own defense strategy by expressing specific determinants/molecules on their own cell membrane to attach host cell-surface. When pathogen adherent molecules adhere to host, it is the critical state of pathogen start to colonize and infect very effectively by utilizing sufficient nutrient from the host. However, many pathogens sense their surrounding environment and can respond by altering molecular gene expression; leads to protective response may follow tremendous tolerating adaptation to a number of stress conditions. This phenomenon is called stress adaptation may intern cause survival capability tin food products and their respective environment. This special property of pathogens can develop specific virulence properties and contribute to survival under number host defense mechanisms. One side elucidating mechanism involved in stress adaptation, the effectiveness of natural and synthetic compounds against food-borne pathogens is the primary requisite for the development of effective control measures will permit implementation of new optimal condition and packaging material for food safety with consumer demand [12]. Even with well-developed technologies and modern food preservatives available also, an excessive amount of food loss due to microbial spoilage specifically the formation of biofilm acting as an obstacle for human and benefit for pathogens. Attachment of these pathogens to food and packaged surfaces by biofilms leads to sever public health risk and great economic loss. The recent work suggested that bacterial cell to cell communication attacked a researcher to manifest role of quorum signals in the attachment of pathogens to food and packaged surfaces. The communication responsible molecule in spoilage food was the one of the hot element to combat the food spoilage process [34]. Consequently, there are a number of advantages using natural compounds in toxicity, availability, and cost compared to synthetic compounds. Synthetic materials showed a vast number of applications, but disadvantages like they are permeable to oxygen; is a special sound in

Table 5 Food packaging material characteristics

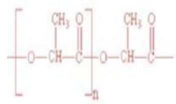
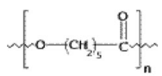
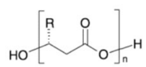
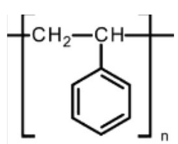
Type of packaging	Material	Structure	Uses/properties	Limitation	References
Synthetic	PLA	Polylactide 	Obtained from polycondensation of D- or L-lactic acid or from ring opening polymerization of lactide, acyclic dimeroflactic acid. Two optical forms exist: D-lactide and L-lactide (natural form); synthetic blend is DL-lactide. It's a hydrophobic polymer due to the presence of–CH3 side groups. steric shielding effect of such side groups makes it more resistant to hydrolysis than PGA. Physical properties and biodegradability of PLA can be regulated by employing hydroxy acids as comonomer component or by racemization of D- and L-isomers [86]. A semi-crystalline polymer (PLLA) (crystallinity about 37%) is obtained from L-lactide where as poly (DL-lactide) (PDLLA) is an amorphous polymer [94]. Their mechanical properties are different as are their degradation times [9]. PLLA is a hard, transparent polymer. PDLLA has no melting point and shows much lower tensile strength [79]	Brittleness and poor thermal stabilities	[9, 64, 79, 86, 94]
	PCL		Poly-ε-caprolactone is a relatively cheap cyclic monomer. A semi-crystalline linear polymer is obtained from ring-opening polymerization of ε-caprolactone in presence of tin octoate catalyst [58]. PCL is soluble in a wide range of solvents. Enzymes and fungi easily biodegrade PCL [18, 90]		[64]
	PHA/ PHB	 PHA;PHB = RisCH_3	Poly(hydroxyalkanoates) (PHAs) out of which poly (hydroxybutyrate) (PHB) is the most common, are accumulated by bacteria as energy and carbon reserves. The properties of PHAs are dependent ont heir monomer composition, which in turn depends on the nature of the carbon source and microorganisms used. PHB is a typical highly crystalline thermoplastic where as the medium chain lengths PHAs are elastomers with low melting points and a relatively lower degree of crystallinity. with respect to food packaging applications-they have low water vapor permeability which is close to that of LDPE. PHB is highly crystalline with crystallinity above 50%. The pure homopolymer is a brittle material	Slow growth of PHA production technologies, Large amount of Raw material needs	[64]
	PS	 Polystyrene	PS(polystyrene) is used to make shape-stable casings for food; as highly rigid packaging can be achieved with lesser thickness, the overall load of a food package can be reduced. the cost is thus reduced. PS can be used to handle frozen as well as hot food products up to 85 °C. It offers high gas-permeability. And has neutral taste and/or smell. Standard polystyrene is never used for packaging since its crystal clear and brittle, therefore BOPS (Biaxially oriented polystyrene) is used instead	High permeability to gases render PS packaging fit for few days. The usage is limited to Trays, food separators, multi packs, etc.	[64]

Table 5 continued

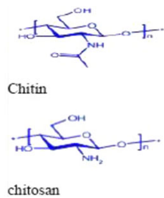
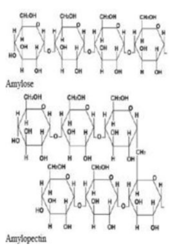
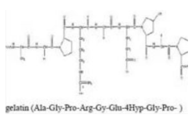
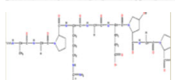
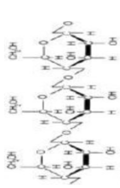
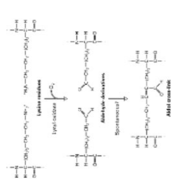
Type of packaging	Material	Structure	Uses/properties	Limitation	References
Natural	Chitosan	 Chitin and Chitosan	Chitin is a polysaccharide in exoskeleton of crabs, lobsters, shrimps, and insects, it can be degraded by chitinase. It is insoluble in its native form, but chitosan-partly deacetylated form of chitin (by action of NaOH/enzymes), is water - soluble. Its polysaccharide consisting of (1, 4)-linked 2-amino-deoxy-β-D-glucan, and deacetylated derivative of chitin. These are biocompatible and demonstrate antimicrobial activity as well as heavy metal absorptivity. Chitosan has been proved to be nontoxic, biodegradable, biofunctional, biocompatible and possess antimicrobial characteristics. It has the advantage of being able to in corporate functional substances like minerals or vitamins and possesses antibacterial activity	Soluble only in slightly acidic medium and effects on casting process	[19, 25, 51, 52, 57, 59, 60, 91, 95]
	Starch	Amylose  Amylopectin 	composed of D-glucopyranos is polymers bound by α-1,4- and α-1,6-glycoside links. These links are formed between the first carbon atom (C1) and (C4) or (C6) of the second one. As the aldehyde group on one end of a starch polymer is always free, these starch polymers always possess at least one reducing tip. Typically consist of amylose and amylopectin. Amylose is linear, where as amylopectin consists of α-1,4-bonded glucose segments, linked by α-1,6 bonds at the branching sites Relatively cheap cost of starch additive sand its availability; biodegradation at a faster rate as well as provides strengthening. Starch-based polymers can also be thermally processed and can under go extrusion, injection molding, compression, and film casting	Loss of mechanical properties due to heat, rapid degradation	[8, 27, 48, 57]
	Gelatin	 Gelatin (Ala-Gly-Pro-Arg-Gy-Glu-4Hyp-Gly-Pro-)	Collagen hydrolysis results in gelatin. Animal protein, consists of 19 amino acids joined by peptide linkages. It's a hydrocolloid that can form a thermo-reversible substance with a melting point close to body temperature; hence are used in edible films/packaging Gelatin edible films reduce the migration of moisture, oxygen, and oil. Gelatin contains a high content of glycine, proline, and hydroxyproline	Do not possess ideal water vapor barrier, mostly contain low molecular weight amino acids and hence low tensile strength	[37, 51, 52, 57]

Table 5 continued

Type of packaging	Material	Structure	Uses/properties	Limitation	References
	Cellulose		Molecular chains forming it are very long and are made up of a single repeating unit (Glucose). Crystalline state. Polymer of high molecular mass and is infusible and insoluble. Cellulose is a cheap raw material; cellophane produced is very hydrophilic and, has good mechanical properties however, it's not thermoplastic	Difficulty in Processing, products inside cannot be heat-sealed	[57]
	Collagen		Collagens constitute about one-third of the total body protein in mammals and are structural proteins of connective tissue of bone, hide, tendons cartilage, and ligaments. Collagen films have found to have excellent oxygen barrier at zero percent relative humidity, but oxygen permeability increases with relative humidity similar to that of cellophane	Relatively lower viscosity, blending needed for tensile strength	[51, 52]

food packaging. That's why scientist thinking to coat wafer-thin layers on plastic for multiple applications in a number of areas. Biopolymers which added a special active nanoparticle (designed with or without natural materials) provides new packaging technology to improve food preservation properties. This is designed to protect the contents from their surrounding and to extend the shelf life of food. Improving oxygen barrier by utilizing many technologies can sound to combat irregular technologies. High density polyethylene (HDPE), Linear low density polyethylene (LDPE), Polycaprolactam (PCL) and Low-density polyethylene (LDPE) applications in controlling food spoilage by cross-linking active natural molecules and suitable enzyme immobilization to polymer exhibited beautiful association between nature and man through technology was proved against S. aureus [53].

Biopolymers

The 'biopolymer' refers to polymers that are generally obtained from natural sources (renewable) and can be degraded by various environmental factors upon exposure (soil moisture, microorganisms, and oxygen), into carbon dioxide, nitrogen, water and other minerals. Polymer materials are solid, nonmetallic compounds of high molecular weights. They contain repeating units called monomer. The properties that are required of an ideal packaging material includes: thermal stability, flexibility, good barrier to gases, good barrier to water, resistance to chemicals, biocompatibility, biodegradability; these are directly affected by the structure of monomer used in polymer preparation. Biopolymers can be classified according to their source [72, 73, 96] and/or method of production as follows:

- *Category 1* Polymers directly extricated from plant or animal biomass or natural biopolymers; includes polysaccharide, protein, and lipids (waxes, glycerides).
- *Category 2* Polymers synthesized from chemical synthesis or synthetic biodegradable biopolymers; includes polylactic acid (PLA).
- *Category 3* Polymers produced by natural/genetically engineered microorganisms or microbial biopolymers; includes poly hydroxy alkanoates (PHA), poly β hydroxy butyrate (PHB) and poly β hydroxy butyrate-co-3 hydroxy valerate, cellulose, xanthan, pullulan [56, 60, 77].

Food Packaging

Packaging materials provide a means to preserve, protect, distribute and store food for a long time. It is

Table 6 Synthetic and natural polymers characteristic features

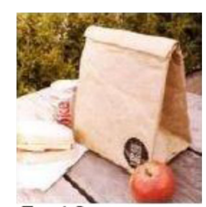
System/type of active packaging	Use	Reagent/substance	Commercial Source	Advantages	Application	Example	References
Oxygen scavengers/absorbers	Control levels of residual oxygen inside food packaging	Iron powder, ascorbic acid, photosensitive dye, enzyme, ferrous salt, unsaturated fatty acid, combinations of these, glucose oxide, metallic and organometallic compounds	Amoco Chemicals, Cryovac Division of Sealed Air, Toppan Printing Company (Japan)	Head space oxygen lowers to as low as 0.01%	Not restricted	Amosorb™,  Amosorb™,  Cryovac OS1000 oxygen scavenging film. CryovacOS1000 oxygen scavenging film	[2, 31, 67]
Ethylene scavengers/absorbers	Control levels of ethylene gas inside food packaging	Silica embedded potassium permanganate, zeolite embedded potassium permanganate, activated carbon impregnated with bromine	Kuaray/Nippon (Japan), Greener (Japan)	Prevents spoilage of food as ethylene ripens fruits and degrades chlorophyll	Can't be used integrated with food or in contact with due to toxicity of bromine gas and potassium permanganate	 PEAKfresh™ PEAK fresh™  Evert-fresh™ Evert fresh™	[26, 62, 67, 78]
Moisture scavengers/absorbers	Control the levels of moisture inside food packaging thereby suppressing microbial growth	Silica gels, molecular sieves, natural clays, calcium oxide, calcium chloride, glycerol modified starch, activated carbon, polyvinyl-alcohol encapsulation	Grace chemical (Davison), Capitol specialty plastics, Sud-chemie performance plastics, Multisorb technologies	Excess moisture is removed	Not restricted	 Tyvek® Tyvek®	[62, 71, 78]

Table 6 continued

System/type of active packaging	Use	Reagent/substance	Commercial Source	Advantages	Application	Example	References
Antimicrobial releasing	Prevents growth rate of microbes	Organic acid sand their salts, acid anhydrides, parabens, chlorides, phosphides, epoxides, sulphides, nitrites, alcohols, ozone, hydrogen peroxides, Diethyl pyrocarbonates, bacteriocins, chelators, enzymes, polysaccharides	Mitsubishi gas chemical (Japan), Microban products	Using inherent antimicrobial property of some polymers	Fresh products like fruits and vegetables	 sanocoat®	[4]
Flavor/odor absorbers and/or releasers	Undesirable Volatile gases, odors and flavors produced resultant of chemical metabolites produced in food are removed from package environment	Activated carbon, sodium bicarbonate	Roche, Armand hammer, Cabot	Makes food more appealing to consumers	Not restricted		[67, 75, 78]

crucial to transport products that need to be safe and wholesome when reaching consumers; hence the quality of food is not compromised. When the food comes in contact with oxygen/moisture etc., its various components undergo oxidation intern oxidative damage leads to food spoilage and become off taste due to microbial contamination. So one of the effective barrier preventing food spoilage by microorganisms and environmental factors is the proper packaging of food may extend the shelf life of food products by avoiding adherence and growth of the pathogen to the packaging material. The packaging industry is the largest user of polymers; more than 90% of flexible packaging is made of them, compared to only 17% of rigid packaging [63]. Unlike rigid (metal cans and glass jars), flexible packaging is relatively permeable to gases, water vapor, and other small penetrable molecules. Therefore, such materials when used for packaging of oxygen sensitive foods it should possess low oxygen permeability and needs essentially high barrier requirement. Materials for polymeric packages must possess numerous characteristics (Table 7) such as mechanical strength, heat resistance, tensile resistance, chemical resistance, and transparency etc. [63].

Justification for Natural and Synthetic Polymers

Many bioplastics are mixes or blends containing synthetic components, that improves its functional properties and hence the finished product can be used for a range of application. Bioplastics have a large number of applications such as agriculture, horticulture, toys, fibers, textiles, medical fields and very importantly in food industries for food packaging application is gaining importance (http://www.european-bioplastics.org). With the context of food packaging, it is important to study the change that occurs on the characteristics of the bioplastics during the time of interaction with the food [84]. Synthetic and natural polymers are opposite in their many properties: polyolefins are hydrocarbon hydrophobic polymers, resistant to peroxidation, biodegradation, highly resistant to hydrolysis which makes them non-biodegradable. Natural compounds, like cellulose, starch and so on, are hydrophilic polymers water wettable or swellable and consequently biodegradable. They are not technologically useful for food packaging, where water resistance is needed. Between these extremes reside the hydro-biodegradable aliphatic polyesters such as polylactic acid (PLA) and the polyhydroxy acid (PHA) [83]. Fully biodegradable synthetic polymers, such as polylactic acid (PLA), polycaprolactone (PCL), and polyhydroxy butyrate-valerate (PHBV) have been commercially available since 1990. Such synthetic polymers are more expensive than petroleum based polymers and also have slow degradability; hence blending starch

Table 7 Characteristic features of active packaging material

Type	Antimicrobial agent	Packaging material	Food
Organic acids	1. Benzoic acid 2. Sorbican hydride 3. Sorbates	PE, LDPE, LDPE, MC/chitosan, starch/glycerol, PE	Tilapia fillets, Simulants, Cheese, Culture media Chicken breast, Culture media
Enzymes	1. Lysozyme, nicin, EDTA	SPI, Zein	Culture media
	2. Immobilised lysozyme	PVOH, nylon, cellulose acetate	Culture media
	3. Glucose oxidase	Fish	–
	4. Papain		–
	5. Lipase		–
Bacteriocins	1. Nicin	PE, HPMC	Beef culture media
	2. Lauric acid	Zein	Stimulants
Fungicides	1. Benomyl	Ionomer	Culture media
	2. Imazalil	LDPE, PE	Bell pepper cheese
Polymers	1. Chitosan	Chitosan/paper	Strawberry
	2. Chitosan, herb extract	LDPE	Culture media
	3. Uv/excimer lazer irradiated nylon	Nylon	
Natural extracts	1. Grape fruit extract	LDPE, Nylon	Beef (grounded)
	2. Clove extract	LDPE Chitosan	Culture media
	3. Eugenol, Cinnamaldehyde	Paper	Bologna/ham
	4. Horse radish extract		Beef (grounded)
	5. Curcumin		–
Gas	Ethanol	Silica gel sachet	Culture media
Essential oils	Clove oil	Clove, Citronella, Cyprus etc.	Food packaging films
Others	1. Silver zeolites	LDPE	Culture media
	2. Antibiotics	PE	Culture media

PE polyethylene, *HDPE* high-density polyethylene, *LDPE* low density polyethylene, *HPMC* hydroxy propyl methyl cellulose, *MC* Methylcellulose

with these degradable synthetic polymers is in focus of research for enhanced applicability in future.

Active Packaging

Active packaging is a system that changes the environment inside the food package by altering its head space to enhance its quality by extending the shelf life, enhancing look, maintaining taste or smell of food product, and mainly avoiding microbial entry is the foremost importance playing in food industries to provide safety food for consumers [70]. In this regard, the growing popularity of active packaging is due to the desire for high-quality safe and natural products amongst consumers [62].

Mechanisms Involved in Active Food Packaging

- Water scavenging from fresh produce that is any minimally processed prepared foods, as a result of normal respiration or microbiological activity, can occur as evaporation from the product followed by permeation through the package material, when a proper water–vapor barrier is not there, Several desiccants' such as silicates (i.e., silica gel) and humidity-controlling salts have long been used in food packaging, particularly to maintain the relative humidity surrounding dry foods and non-food products. Silica gel, its moisture-absorbing rate, and the water vapor transmission rate are dependent, usually at a very low relative humidity.
- Oxygen scavenging leads to various adverse effects on food/beverages and deteriorates nutritional and quality of food. Some are listed as follows (a) Rancidity due to oxidation of unsaturated fats present in food material; may lead to formation of toxic products. (b) Loss of vitamin C (ascorbic acid) (c) Browning of meat products (d) Proliferation of aerobic spoilage causing microorganisms (e) Off-odors from bakery products (f) Growth of insects/insect eggs. (g) Increase in

respiration of fresh produce. (h) Phenol induced browning in freshly cut vegetables and fruits. Mechanisms involved in active food safety: oxygen scavenger refers to materials incorporated into package structures, that chemically combine with, and thus effectively remove, oxygen from the inner package environment; ultimately removing oxygen from the food product through diffusion, resulting from differential partial pressure. Scavengers are fast, high capacity oxygen interceptors which are capable of eliminating relatively large volumes of oxygen and continuing till the scavenger is present.

- Antimicrobial compounds have been incorporated into films for use in active packaging. These are included in active packaging because they rely on diffusion through the packaging medium instead of a triggered release of antimicrobials through responsive materials [14]. Edible and non-edible films are also of interest wherein natural antimicrobial ingredients like clove, pepper, cinnamon, coffee, and others are incorporated [40, 55]. Chitosan, another biologically derived polymeric biomaterial, is also being researched extensively due to its inherent, natural antimicrobial activities and non-toxicity [3, 46, 93].

Nanotechnology in Food Packaging

New food technologies are always creating a tremendous curiosity in the food industry. Scientist continuously working hard for developing food application methods for public use, health concern and economic status of the country. The most promising benefit of hot nanotechnology near future for food industries. Research and development (R&D) in the area of nanotechnology continuously extending the shelf life of food and drinks by improving the safety. One of the promising active areas in food packaging is smart packaging by use of nanotechnology to develop active antimicrobial packaging. Packaging material incorporates ‘smart’ nano molecules which respond to environmental alterations, intern alert itself or alert consumer. In this regard scientists working at big name companies like Bayer, Kodak, and Kraft as well as a number of universities, smaller companies putting hand together to develop smart food packaging material to absorb oxygen, detect pathogen associated with food and at the same time to alert consumers for spoilage food. Now *E. coil* and Salmonella detecting smart packaging material is ready to release in few years. According to the industry analyst, the current market for this technology in the US is estimated that $58 billion at the end of 2015. Similar technology was developing for US government by Netherlands using smart packaging nanotechnology that will not only detect when food is beginning to spoilage but will also release preservatives to food to extend the shelf life food. So, this type of solutions is some of the tremendous innovations in the food industry today. Many other applications attacked a number of researchers in the field of food packaging, food processing, agriculture and other fields with interesting mechanism discussed broadly [11, 15, 16].

Nano/biomimetic Adhesives

The utilization of potent tissue adhesives in aqueous environments is a big challenge. Absorbed water can diminish the physical surface adhesion forces and acid–base interactions, which leads to changes in the chemical bonds. Therefore, tissue adhesives should be resistant to the aqueous environment of the body fluids. Synthetic and natural derived adhesives materials show some disadvantages regarding their adhesion properties on wet substrates. One of the great alternatives for adhesive material utilization under the aqueous condition is Biomimetic adhesives. Two great sources for biomimetic adhesives inspired from nature are, from some animal feet to surfaces (such as geckos and frogs) and some ocean creatures based on biochemical secretion along with having nano structural features. Emphasize on the importance of inspiration from the nature for designing new adhesives and review recent research in this field which is rapidly expanding.

From Marine Creatures

Brown Algae Brown algae release a viscous adhesive established on carbohydrates that contain polysaccharides and glycoproteins. Also, phenolic polymers play an enormous function in brown algae’s adhesion to hard surfaces. The composition of polyphenols consists of phloroglucinol items which act much like DOPA residues of tube worms and mussels seeing that they can type go-hyperlinks by way of oxidation. Actually, the alginate founded adhesives are inspired from and similar to algae adhesive. This adhesive has a merit that it adheres well to both hydrophilic surfaces equivalent to collagen sheets and to hydrophobic surfaces akin to plastic. Novel biomimetic glue has been studied on already with an adhesion mechanism just like the adhesion of algae composed of alginate gel and native phloroglucinol [13].

Mussels Mussels produce byssus to adhere themselves to the various surfaces in their environment. Byssus consists of protein threads hooked up to the mussel’s foot where there is a flattened plaque at the end which is an interface for adhesion to the surface. The animal has 4 distinguished glands in its foot that secret targeted products and these products form the plaque. These products include a mucous material, a collagenous layer, a combination of poly phenolic proteins often called foot proteins, and an adjunct protein. The chief similarity between these proteins is the existence of 3, 4-dihydroxyphenylalanine (DOPA), a modified amino acid, which cross-links the proteins and acts as an arbitrator in adhesion to the surface. The oxidative conversion of DOPA to DOPA-quinone enables the adhesive proteins to cross-link. A great advantage of this adhesive is its sufficient mechanical strength of adhesion under the wet conditions and the ability of adhesion to a wide range of materials such as metals, plastics, and glasses.

Nano-biomimetic Adhesives In nature, complicated topographical floor designs, with reversible adhesion to enhance physical interactions were determined in some animals. Two magnificent designs are fibrillar pads determined in gecko feet, and tender pads determined in tree frog feet. A gecko's pad includes long keratinous hairs (setae) which have a length of 30—a hundred thirty mm. These hairs incorporate thousands of nubs ended via 200–500 nm spatula-shaped structures. The attachment pads of tree frogs incorporate a hexagonal sample of 10 mm epithelial cells. 1 mm vast channels separate the cells and divide them into an array of nanopillars (>300–400 nm in diameter). The fibrillar attachment pads show up in various geometrical shapes in these animals. For example, toroidal, flat, sucker-like, band-like, spatula-like, filament-like, spherical, and conical tip shapes were located in this case. These distinctive geometries furnish the reversible adhesion of the animals to each dry and wet surfaces. Utilizing nano/micro fabrication procedures equivalent to nanoimprint lithography (NIL) and electron beam lithography (EBL), surfaces with identical geometries were designed in latest years.

Gecko The capacity of geckos to connect to hard, tender, vertical, and reverse surfaces ended in researches about the adhesion mechanism of gecko toes and utilizes it in adhesive systems. The compact fibrillar arrays which quilt the bottom of gecko ft develop the outside adhesion to its highest. The adhesion of animal feet to a floor is managed with the aid of a combination of capillary and van der Waals forces. In recent years, situated on these results, adhesives influenced from the gecko for use in moist environments akin to quite a lot of tissues have been developed with a view to connecting to organic surfaces effectively by creating reversible non-covalent bonds below water. There had been attempts to mimic the fibrillar structure of gecko ft via utilizing strategies like lithography and dry etching in oxygen plasma on micro patterned poly (imide) films [66].

Frog The Australian frog (*Notaden bennett*) secretes a protein-based adhesive on its again when sensing a threat. This adhesive is strong, bendy, potentially biocompatible, and sets in water. A number of fascinating critiques were achieved on this adhesive to show its benefits in special biomedical purposes. This adhesive used to be applied on a sheep cartilage with the intention to repair it. The results illustrated that this adhesive had a better effect compared to fibrin/gelatin adhesives and weaker force in assessment to cyanoacrylate adhesives on this tissue. Remarkable antibacterial and healing results were observed in a system of frog skin powder on wounds. In one more gain knowledge of, it used to be recognized that a peptide with the capacity of promoting the wound remedy process exists in the dermis of the *Odorrana graham* frog. Its fascinating pastime was found in a full thickness dermal wound, created in a murine mannequin [35, 47]. Researchers have proven that the biocompatibility and biodegradability of this adhesive are favorable despite the fact that the researchers on this adhesive are still being endured to check the distinct adhesion mechanism and the role of proteins involved in the mechanism.

Conclusion

Currently, when the environmentally safe and sustainable development is crucial to the social research, production, and utilization of (bio)degradable polymers becomes an increasingly important issue. Biopolymers have vast diversity, and therefore their applications in food packaging are various and multiple. This review covers the major concerns about the botanicals sources and its applications, natural and synthetic polymers and nanotechnology based applications in food packaging, their structure, and sources also elaborated systematically. It is clear that bio-based packaging materials offer a versatile potential in case of packaging industry however, there is need of certain storage tests to be performed on packaging machinery in order to certify the use of these packaging films on a commercial scale. So in future, critical evaluation is required to access the functionality of bio-based packaging materials before they are launched into the market as sole substitutes for conventional packaging materials.

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