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REVIEW

Moisture absorbers for food packaging applications

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Abstract
Even though moisture in food products is useful for the quality of foods, excess moisture in a package is unfavorable to the quality of the food product and the integrity of the package, particularly in the case of high water activity food such as fresh produce and raw meat. In those cases, including moisture absorbers in food packages is helpful. The common process involved in moisture absorption in food packages is physical adsorption. Here, the moisture absorption capacity is reviewed with respect to packages containing high water activity food. The applications of moisture absorbers in food packaging are discussed regarding the benefits achieved and their effectiveness. An overview of various types of moisture absorbers, their forms, and packaging material applications is provided. Particularly, the benefits of moisture absorbers for specific food products are reviewed.

Keywords Moisture scavenger · Fresh produce · Absorption · Active packaging · Modified atmosphere · Micro-perforated film

Introduction

Packaging plays a significant role in the food distribution. Packaging encounters the essential need to preserve food quality and safety from manufacturing to final consumption by inhibiting any unwanted chemical and biological changes (Gaikwad et al. 2017a; Singh et al. 2018a; Choi and Lee 2013). Consumer awareness of the importance of eating safe and healthy food is increasing. Specifically, apprehension about the safety and preservative content in food has received much attention. Therefore, increasing demand for naturally high-quality foods, which are non-processed or nominally processed, and not comprised with preservatives, but offer an adequate shelf life to food (Gaikwad et al. 2018a; Singh et al. 2018b). In response, the protecting function of the package has been advanced and enhanced important to the development of novel packaging technologies, such as modified atmosphere packaging (MAP), active packaging, and intelligent packaging (Yildirim et al. 2018; Gaikwad et al. 2018b; Biji et al. 2015; Hussein et al. 2015). Food packaging structures have diverse functions, which includes avoiding containment, facts/information, and marketing. The primary functions of packaging is to separate food from the surrounding environment, reducing exposure to spoilage factors (e.g., microorganisms, oxygen, water vapor, and off-flavors) and avoiding losses of desirable compounds (such as flavor volatiles), thus extending food shelf life (Gaikwad et al. 2017b). Active and modified atmosphere packaging technologies deliver all these functionalities and several other new solutions for extending the shelf life and maintaining the nutritional quality and safety of food (Ahmed et al. 2017; Illeperuma and Nikapitiya 2006).

A key reason for food spoilage is the existence of moisture/water in the food (Yildirim et al. 2018; Mahajan et al. 2008). The accumulation of excess relative humidity (RH) due to moisture inside the package of high water activity foods such as fish, poultry, meat, and fresh produce accelerates the growth of bacteria and mold, which further leads to nutritional and quality loses of food. The control of high moisture inside the food package is essential to defeating microbial growth and for improving the food sensory attributes. Many dry food products are sensitive to relative humidity during the storage period, and even presence of

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low relative humidity inside the packages may cause significant quality loss. The increase in moisture makes the food product more susceptible to microbial growth and may cause changes in texture and appearance, therefore reducing the shelf life of food (Murmu and Mishra 2018; Choi and Lee 2013). For high water activity-based products, such as fresh fish, raw meat, and fresh produce, keeping a controlled high RH level inside the package is beneficial in preventing drying. In addition, excess liquid caused by drip loss due to muscular degradation and storage temperature fluctuation is common for raw fish and meat. Consumers observe liquid in a package as reducing the attractiveness of a packed product making it less required (Rux et al. 2016).

An effective way to control this excess moisture development inside the package is to use a moisture absorber. Moisture absorber regulates water activity of the product to suppress the microbial growth (Choi and Lee 2013). The common form of moisture absorbers is sachets, films, tray and pads which usually employed to maintain fluid exudates from food products or to maintain the relative humidity inside the package. Moisture absorbing/scavenging materials are usually contained inside sachets and pads for food packaging application that is added to the package to regulate the excessive moisture from the food which saturates in the package during storage. Absorbers react with moisture via physical adsorption of a moisture absorbing material. The approaches for the moisture regulation can be classified into three main categories: firstly, reduction in moisture (via MAP through swapping the humid air in the headspace with dry modified atmosphere (MA) gas, or via vacuum packaging in which the removal of humid air from the headspace), secondly, moisture prevention (by high barrier packaging), and third, moisture removal (by using moisture absorber). The percentage of relative humidity levels inside packages can also be controlled by the proper selection of packaging materials having a high barrier against water vapor (Bovi et al. 2018).

While there has been great interest and developments in the field of oxygen scavenging packaging (Gaikwad et al. 2017a; Choi and Lee 2013), comparatively very little attention has been paid to moisture absorbers (Fig. 1). Hence, this review paper aims to provide an overview of moisture absorbers used for food packaging applications. We first discuss the significant types of moisture absorbing materials, their mechanism, major types of polymeric films in humidity regulations application, trends in moisture absorbing packaging systems, and classification of moisture absorbing system by food type. Then, we provide an overview of food applications, which is future perspective for the moisture absorbers.

Classification of moisture absorbers

In principle, moisture absorbers comprise various hygroscopic substrates or substances to attract and hold water molecules from the surrounding environment. They are generally hygroscopic substrates or substances. Active moisture absorbers can be further divided into two main categories: RH controllers that absorb humidity in the package headspace, such as desiccants, and moisture removers that absorb exuded liquids from food products (Yildirim et al. 2018).

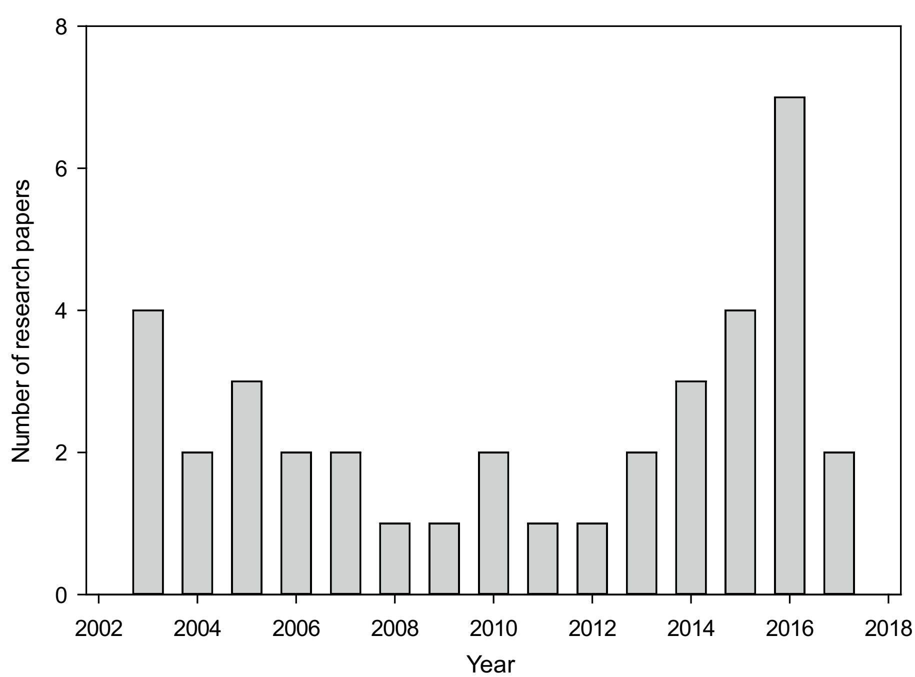

Fig. 1 Number of research papers on moisture absorbers for food packaging applications from 2003 to 2017. Data collected from Scopus using the keywords *Moisture absorber packaging*, *Moisture absorbers*, and *Moisture absorbing film*

The latter can be applied in the form of pads and sheets and are typically placed below fresh products and meat in different packaging concepts. Price, safety, and the moisture absorption capacity restrict the range of candidate substance for food packaging applications. In recent years, some novel superabsorbent composite materials have received great attention, including organic- and polymer-based composite materials. Some potential moisture absorbing materials by their nature for food packaging applications are classified in Table 1. Even though most commercial moisture absorbers are constructed from desiccants for high water activity food, the moisture absorbing film industry has become increasingly interested in the development and application of novel absorbing materials in the polymeric film form.

Organic based

In recent times, researchers from academic as well as from industries have focused on the production and use of organic-based moisture absorbers for moisture absorbing packaging (Gaikwad et al. 2018a). Organic-based moisture absorbers present potentials for forming new packaging systems with many required qualities and advantages for consumer perception and sustainability. Several novel

Table 1 Examples of commercially available moisture absorbing packaging for food packaging

Company	Trade name	Polymer matrix	Product form	Application
Kyodo Printing Co., Ltd., Japan	MOISTCATCH™	PET/AL/moisture absorbing layer/sealant layer	Film	Meat products
BOSSPACK Co., Ltd., Korea	MOSSPACK	Linear low-density polyethylene	Film	Dry and crispy products
CSP Technologies, USA	Activ-Film™	Linear low-density polyethylene	Film	Fruits and vegetables
Maruto Sangyo Co., Ltd, Japan	MoistPack	PET/Al foil/polyethylene/layer/polyethylene	Film	Moist food
Peakfresh Products, Australia	Peakfresh	Low-density polyethylene	Film	Fruits and vegetable
BASF Chemical company, Germany	Luquasorb®	Sodium polyacrylate	Film	Food packaging application
Nordenia International AG, Germany	Nor® Absorbit	–	Film *(Microwavable)*	Moist food
Sorbed India, India	SORBED India™	Linear low-density polyethylene	Film	Meat and meat products
CSP Technologies, USA	Fresh-R-Pax®	Polyolefin	Tray	Fruits and vegetables
SEALPAC Germany	Tenderpac®	PET	Tray	Meat products
Laizhou Guoliang Packing Products Co., Ltd. China	GUOLIANG	Eco-friendly polystyrene	Tray	Processed aquatic and meat products
RossPack, Russia	Water-absorbing tray M-3	Expanded polystyrene	Tray	Moist food
Paper Pak Industries, USA	UltraFreshSystem	PET	Tray	Fresh produce
Sealedair, USA	Dri-Loc®	Linear low-density polyethylene	Pad	Meat, fish, fresh-cut produce, etc.
SOCO Chemical, China	SOCO®	Low-density polyethylene	Pad	Chicken, fish, fruit, vegetable, pork and beef meet
Sealedair, USA	Cryovac® Absorbent Pads	Renewable resources	Pad	Meat, fish and poultry products
C-Airlaid Company, Russia	C-Airlaid	Polyethylene-laminated	Pad	Frozen and chilled meat, fish and their semicooked products
Sirane Ltd, UK	Dri-Fresh	–	Pad	Fruits and vegetable
McAirlaid Inc., USA	MeatGuard	–	Pad	Raw meat
Swiss Pac Pvt Ltd, India	AGELESS	–	Sachets	High water activity food
Shenzhen Chunwang Environmental Protection Technology Co., Ltd., China	CHUNWANG	–	Sachets	Food and pharmaceutical products
Multisorb Technologies, USA	FreshPax® Packets	–	Sachets	Moist and dry food

PET polyethylene terephthalate, *AL* aluminum moisture absorbing especially superabsorbent composite materials in the form of film and tray have been studied in the past few years. The use of natural moisture absorber entrapped in a polymer matrix will be the focus of future work. Possible absorbers include food grade such as fructose and sorbitol, which is the interest to the researcher.

Fructose is a hygroscopic material which can absorb moisture from the environment. It initiates to absorb water vapor from surrounding at about 55% RH. It has acceptable humectant properties. Fructose can retain moisture for a long period, even at low RH (White 2014). Recently, Bovi et al. (2018) developed Fruitpad containing fructose for the packaging of fresh strawberries. The fructose was incorporated to Fruitpad to increase overall moisture absorption capacity. The Fruitpad containing 30% fructose exhibited the highest amount of moisture absorption in a package that is 0.94 g of water/g of pad stored at 20 °C and 100% RH. The results showed that strawberries packed with Fruitpad containing fructose had less than 0.92% weight loss. Sorbitol is a food-grade moisture absorber and approved by FDA (Food and Drug Administration), USA. Sorbitol occurs naturally, and it is also manufactured synthetically from glucose. The use of sorbitol has already been applied in different fresh produce such as green tomatoes, mushrooms, and broccoli, extending their shelf life and suppressing microbial growth (Shirazi and Cameron 1992). DeEll Jr. et al. (2006) studied the incorporation of sorbitol powder in modified atmosphere packaging permitted better maintenance of physical and nutritional quality of broccoli heads in comparison with the control sample (without sorbitol). Roy et al. (1995) studied the use of sorbitol as a moisture absorber (Ratio: 15 g sorbitol/100 g mushrooms) to regulate in-package relative humidity mushrooms at 10 °C. Results showed that the desiccant added into the package increased the shelf life of the product and higher sorbitol quantities in the package increased product weight loss. Cellulose and their derivatives are also explored as a moisture absorber by various researchers for food packaging applications (Pinming et al. 2016). The carboxymethylcellulose (CMC) can absorb nearly eight times greater than the standard cotton. However, the disadvantage of CMC is its low resistance to decomposition, insects, and light (Boruvkova and Wiener 2011).

The main disadvantages of the organic-based moisture absorbers are relatively higher expensive and have lower absorbing capacity in comparison with inorganic-based absorbers, therefore bigger sachets than the traditional silica gel descants. However, more research must be done to expand technical and commercial possibility, including prolonging the stability of materials during processing as well as efficiency for moisture absorbance.

Inorganic based

Inorganic-based moisture absorbers are the largest segment of the market and have traditionally been used as a water absorbent. For those food products that need very low relative humidity, sachets containing calcium oxide (CaO), silica gel have typically been used (Yildirim et al. 2018), and other materials including silica gel, calcium chloride ($CaCl_2$), potassium chloride, potassium carbonate, bentonite are most common moisture absorbers for food packaging applications due to its non-toxic and non-corrosive nature. The general reaction of calcium oxide with water is as given,

$$CaO + H_2O \rightarrow Ca(OH)_2 \tag{1}$$

The high thermal resistance properties of these absorbing materials permit their incorporation into polymeric matrix via melt extrusion process to produce plastic/desiccant-based moisture absorbing structures. Some companies are manufacturing these types of structure for use in films, trays, and so on. MOISTCATCH™, Dri-Loc®, AGELESS, and CHUNWANG are an example of commercial moisture absorbing sachets, and MoistPack, Luquasorb®, and Fresh-R-Pax are available in tray form which is made from inorganic-based moisture absorbing material for food packaging applications. Chiba et al. (2011) developed moisture absorbing film based on low density polyethylene (LDPE) and zeolite for food packaging applications. The author claimed that the packaging film achieved a saturation reaching the time of moisture absorptiveness of the containing desiccant of 100 days or more. Kia (2010) developed a low-moisture absorbing sheet containing calcium carbonate-coated acrylonitrile and polyvinylidene chloride (PVDC). The developed composite showed the highest moisture absorption (3.4 wt%), where talc coated at 0.08 wt% has the lowest moisture absorption.

The water sorption capacity of zein powder and zein films using the extrusion method was studied by Wang and Padua (2004). Extruded film samples showed less moisture compared to zein powder; further zein films containing plasticizer (oleic acid) exhibited a further reduction in moisture uptake by zein film the. Water vapor permeability of extruded zein films was strongly affected due to a relative humidity of the testing environment. Higher relative humidity resulted in higher water vapor permeability. Aharoni et al. (2007) utilized Xtend® (StePac, Tefen, Israel), a co-extruded packaging film, and stated that Xtend® films could effectively modify both atmospheric composition and RH condition in the package containing various fresh produce. Azevedo et al. (2011) developed desiccants with calcium oxide, sorbitol, and $CaCl_2$ in a range of 0.2–0.6 g of desiccant mass in varying proportions. The variation in the moisture content of each mixed desiccants was evaluated at regular intervals till 5 days at 10 °C. Results indicated that developed desiccant mixture contained 0.5, 0.26, and 0.24 g g^{-1} of CaO, $CaCl_2$, and sorbitol, respectively, and had a moisture holding capacity of 0.813 g water $g^{-1.}$

Polymer based

Polymer-based moisture absorbers are the new area of attention for the packaging material manufacturers. They include a base polymer suitable for packaging applications that are modified with a polymer-based moisture absorber. The list of different commercially available oxygen scavenging plastic films for food packaging applications is presented in Table 2. Various researchers have studied polymer-based moisture absorbers, such as starch copolymers, polyacrylic acid, polyvinyl alcohol, and cellulose-based biopolymers. Polyvinyl alcohol (PVA) is a biodegradable and hydrophilic polymer in nature and commonly used in packaging applications since they possess excellent film forming, biodegradability, acceptable mechanical, and oxygen barrier properties (Chen et al. 2018; Srinivasa et al. 2003).

Moisture absorbing film based on polyvinyl alcohol adding into low-density polyethylene (Ding et al. 2008). Result exhibited that the PVA added in LDPE showed good moisture absorption property for food packaging applications but poor mechanical properties. Shi et al. (2008) studied the moisture sorption characteristic of PVA films impregnated with starch for active food packaging applications to be appropriate for packaging applications. Chen et al. (2018) developed active packaging film with functions of moisture absorbing as well as antioxidant properties based on polyvinyl alcohol and green tea extract. Results showed that the neat PVA film showed 29.25% moisture sorption; further, this film is utilized for packaging of dried eel and it is found that the film containing 2% green tea extract showed the best quality protective efficiency to prevent the dried eel from absorbing moisture and oxidizing of lipid. Polyacrylic acid-based water absorbent resin was developed by Matsumoto et al. (2018) by convenient production method and claimed an acceptable amount of moisture absorbing property.

Cellulose is the most abundant organic-based polymer. Cellulose and its derivatives including carboxymethylcellulose (CMC) were utilized to prepare moisture absorbing film for food packaging applications. Guo et al. (2018) studied water vapor sorption performance of two nanocellulose films that is TEMPO-oxidized cellulose nanocrystal film and sulfuric acid-treated cellulose nanocrystal film. The results confirmed that the film had equilibrium moisture contents of 28 and 22%, respectively, at an RH of 95% storage condition. A polymeric film based on cellulose-based NatureFlex™ (Innovia films, Cumbria, UK) exhibited a good perspective for fresh produce packaging application since the film has a very high water permeability as against the conventional polypropylene (PP) films (Madonna et al. 2018). The water vapor transmission rate of cellulose-based NatureFlex™ packaging films has been shown to increase with the increase in relative humidity. Hence, precaution must be taken while designing fresh produce packaging system as extremely high water permeability can lead to higher food moisture and weight loss.

Mechanism of moisture absorption

Several mechanisms in both organic and inorganic have been studied in moisture absorbers by the researchers (Wilson 2017). The key considerations when developing profitable technologies are not only the technical factors, e.g., absorption capacity, rate, activation mechanisms, reaction end, derivatives, potential interactions or reactions with the other functional packaging technologies, and food product, but also regulation and marketing issues, e.g., food safety, cost, and consumer acceptance. Moisture absorbers are those materials who physically absorb and hold water molecule from the surrounding environment and, on the other hand, moisture scavenger, where water absorption is by means of a chemical reaction between two functional materials. Dry desiccants can absorb moisture from environment both by physical and chemical adsorption, and hence decrease

Table 2 Classification of moisture absorbing materials for food packaging applications

Classification	Moisture absorbing materials
Inorganic	Silica gel, natural clay (montomorillonite, zeolite), calcium chloride, magnesium chloride, aluminum chloride, lithium chloride, potassium acetate, calcium bromide, calcium nitrate, zinc chloride, phosphorus pentoxide, activated alumina, calcium oxide, barium oxide, sodium chloride, potassium chloride, potassium carbonate, ammonium nitrate, bentonite, sodium hexametaphosphate
Organic	Sorbitol, xylitol, fructose, cellulose and their derivatives (sodium carboxymethyl cellulose, potassium carboxymethyl cellulose, ammonium carboxymethyl cellulose, monoethanolamine carboxymethylcellulose), diethanolamine or triethanolamine
Polymer-based	Starch copolymers, polyvinyl alcohol, absorbent resin
Other synthesized	Starch-grafted sodium polyacrylate, acrylamide synthesis attapulgite, diatomaceous earth

the relative humidity in the headspace of the sealed pack. Moisture absorption by silica gel is an example of physical moisture adsorption, and sorption by calcium chloride is an example of a chemical reaction. In general, the use of moisture absorbers is most common for food packaging applications.

Choi and Lee (2013) evaluated synthesized attapulgite as a moisture absorbing material. Attapulgite is a hydrated octahedral covered magnesium aluminum silicate absorbent mineral (structure as presented in Fig. 2). Attapulgite has exchangeable cations and reactive –OH groups on its surface. Hence, the addition of attapulgite into a polymeric matrix, especially in polyacrylic acid, could increase moisture absorbency as well as swelling rate compared to other natural clays (Zhang et al. 2009). In case of organic-based moisture absorbers, cellulose is the widely studied material as a tendency to moisture absorbance, and cellulose is categorized as a hygroscopic material, owed to a number of possible water molecule adsorption sites at hydroxyl groups (–OH) and carboxyl groups (–COOH). Moisture absorption in cellulose can take place on either the surface or all over the bulk of disordered regions, commonly denoted as amorphous regions in cellulose (Boruvkova and Wiener 2011). Studies have found that moisture penetrates through the amorphous regions of cellulose; on the other hand, it penetrates much low amount into crystalline regions (Guo et al. 2018).

Recently, the use of derivatives of cellulose especially sodium carboxymethylcellulose (CMC) in the active packaging material is getting attention due to their excellent film-forming properties. CMC is a polar macromolecule compound and its degree of moisture absorption subject to the relative humidity, and the presence of some polarity group. The higher the number of polarity group, the degree of moisture absorbing is high. Although the moisture absorption by cellulose causes deformation of macromolecular structure and ends the advantage of the dimensional stability of cellulose, it produces a unique pathway for their use as a moisture absorbing material, which has recently been used in an increasing number of active packaging areas.

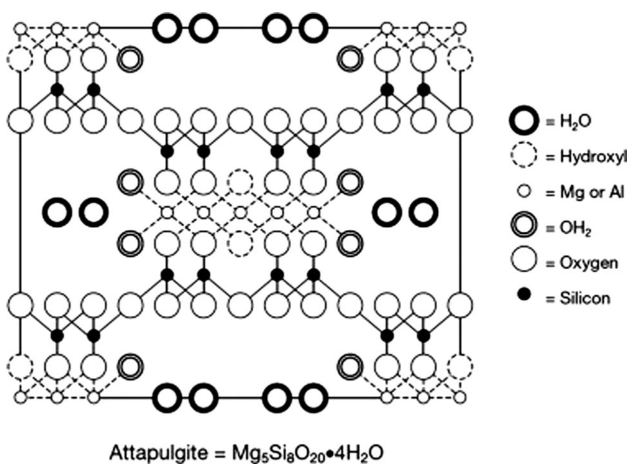

Fig. 2 Attapulgite structure with complex magnesium, aluminum silicates with an open-channel structure. (Adapted from Choi and Lee 2013)

Forms of moisture absorbers

Moisture absorbing materials absorb the in-package moisture and free water, leading to a lowering of relative humidity to a point at which condensation no longer takes place. The amount of water absorbed in a closed package can be influenced by (a) the type and volume of used absorbing material; (b) how strong the water molecule is bound to the source; (c) the amount of water that has already been absorbed by the absorbing material, as well as temperature (Bovi and Mahajan 2017). The moisture absorption capacity of material should be considered along with the intended product application and expected shelf life when designing a moisture absorbing packaging system for food having high water activity. For food packaging applications, the most commonly used forms of moisture absorbing packaging systems are sachets, pads, humidity-regulating trays, and polymeric films as shown in Fig. 3. The commercially well-established technologies incorporate the use of sachets, or pouches, and pads that do not affect with the structure of exterior packaging materials.

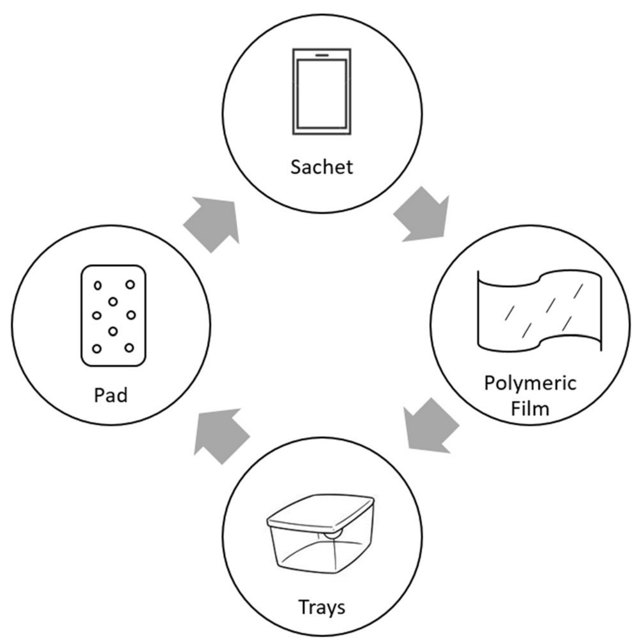

Fig. 3 Different forms of moisture absorbers for food packaging applications

Sachets, bags

Moisture absorbing packaging systems in the form of sachets are commonly used to keep low levels of moisture in dried food packages, for example meat, nuts, spices, biscuits, sweets, crackers, milk powder, and instant coffee to decrease water activity and inhibit mold, yeast, or bacterial growth (Yam 2010). In this category, moisture absorbers are in forms of powder, granules, beads, blocks typically packed in a porous sachet or bag. Silica gel, dry sorbitol, xylitol, sodium chloride, potassium chloride, and calcium chloride are the most common absorbing materials used in the sachets form. The commercial moisture absorbing sachets used to absorb and/or control moisture inside food packages are Desi Pak, Desi View, Sorb-It and 2-in-1 (United Desiccants, USA), Ageless (Swiss Pac Pvt. Ltd, India), MiniPax, FreshPax® StripPax, Natrasorb (Multisorb Technologies, USA), Chunwang (Shenzhen Chunwang, China), and the moisture absorbing label Desimax (Multisorb Technologies, USA). Moisture absorbers in the form of granules or powders should not expose directly to an environmental atmosphere where relative humidity is high.

The important factors to study when evaluating the type of desiccant-based sachets and calculating the capacity to keep moisture balance between equilibrium relative humidity in the headspace to the optimum water activity of packaged food are: equilibrium adsorptive capacity, the rate at production, or storage temperatures. Sachets that carry moisture absorbers comprise with powder form absorbing materials placed inside a high-permeable material (sachet material), which was heat-sealed to form the sachet. The materials used to make a sachet must resist handling and distribution to avoid failure and leakage of the absorbing material. Sachets are generally placed alongside food products inside an enclosed system, divided by the external environment by an exterior packaging that contests specific permeability requirements contingent upon each application, in an effort to adjust the moisture composition within the packaging headspace. Packaging materials for sachet are essential to be either highly porous or semipermeable to a water molecule. Numerous materials have been utilized to overwrap materials for sachet making purposes, for example semipermeable polymer films, perforated barrier films, porous nonwoven fabrics, and papers (Ozdemir and Floros 2004).

Main drawbacks of sachets as food contact materials; it negatively affects the composition and the sensory properties of the packaged food and the risk of accidental rupture of the sachets as well as inadvertent consumption of their contents (Gaikwad et al. 2018a).

Moisture absorbent pads

The moisture absorbent pads are mostly used at the bottom of polymeric trays or containers to absorb the exuded fluids from food during the storage period and temperature fluctuation during transportation. Otherwise, absorbent pads have been placed in bags for displaying food items (Ren et al. 2018). Food products that may be found in the market placed in this packaging system include raw meat, poultry, fish, or shellfish and fresh produce (Choi and Lee 2013). Principally, the absorbent pad must contribute to extend the shelf life of packaged food and to retard microbial growth. Some examples of commercial pad available in materials are shown in Table 2. Absorbent pads are already successfully well established in the market especially for the packaging of raw meat and products (Yildirim et al. 2018). Commercial moisture or drip-absorbent pads are generally supplied in the form of sheets of different sizes to match the tray and anticipated drip loss of different food products (SOCO®, SOCO Chemical, China; Cryovacs® Dri-Locs®, Sealed Air Corp., USA; C-Airlaid, C-Air laid, Russia; Toppan Sheet®, Toppan Printing, Japan; Dri-Fresh, Sirane Ltd., UK; Meatguard, McAirlaid Inc., USA; SupaSorb®, ThermaRite Pty.; Luquasorb®, BASF, Germany; Fresh-R-Pax, Maxwell Chase Technologies, USA; UltraZap®, Paper Pak Industries, USA). The typical structure of the food packaging system containing moisture absorbent pad is shown in Fig. 4. Moisture absorbent pads primarily comprise of granular or powder form a superabsorbent polymer, such as polyacrylate salts or graft copolymers of starch, and or high-moisture absorbent paper located in between two sheets of a microporous or nonwoven polymer. The moisture absorbing polymer can absorb 100–500 times its weight of liquid water, depending on salinity (Otoni et al. 2016). The multipurpose water absorber pads can be designed to remove drip loss leaking from raw meat, which in turn trigger the active functions

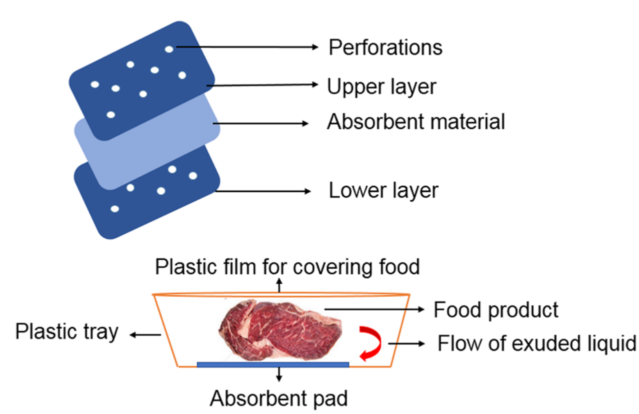

Fig. 4 Scheme of the food packaging system with moisture absorbent pad

such as antimicrobial properties, pH decreasing, and odor absorption (e.g., UltraZap® OdorVac, Paper Pak Industries, USA) (Yildirim et al. 2018). Moisture absorbing pads are not frequently considered to be active packaging. As per the European Union (EU) Guidance to the Commission Regulation (EC) No 450/2009, "Materials and articles active on the basis of the only natural constituents, for example pads composed of 100% cellulose, do not comes under the definition of active materials since they are not considered to incorporate constituents that would release or absorb substance deliberately."

Even though traditional moisture absorbent pads have been commercially well established for food preservation, packaging systems provided with them may have some drawbacks regarding food preservation. Kannankeril and Cruikshank (1993) specified that the moisture absorbent capacity of the pad may be restricted by the total mass of the packaged food, not allowing absorbing all the liquid exuded by the food. One more drawback is the perforation of the outer layers of the absorbent pad. These layer perforations must be delivered in a suitable distance to avoid film tearing, thus releasing the absorbent material.

Humidity-regulating trays

Most of the plastic materials used in packaging of fruits and vegetable packaging have lower water vapor transmission rates compared to the transpiration rate of fruits and vegetables. Hence, the level of relative humidity increases, as well as condensation of water, occurs inside the package. The use of plastic trays for food packaging applications is increasing steadily from the last few years (Gaikwad et al. 2017c). The key reasons for its popularity are their glass-like transparency, acceptable gas barrier, lightweight, and shatter resistance. The incorporation of moisture absorbing materials into the polymer matrix of packaging tray offers a new approach for regulating humidity of packaged food products. A wide range of polypropylene (PP), polyethylene terephthalate (PET), expanded polystyrene (EPS), polystyrene (PS) trays are used for fresh produce as well as fresh meat packaging applications. Moisture absorbing trays comprising an inbuilt high-capacity absorbing materials are available for packaging high water activity-based foods (LINPAC Packaging Ltd). Some commercially available humidity-regulating trays are Fresh-R-Pax® (CSP Technologies, USA); Tenderpac® (SEALPAC, Germany); UltraFresh-System (Paper Pak Industries, USA). These polymer-based trays are manufactured by the process of thermoforming.

Rux et al. (2016) developed humidity-regulating trays with thermoformed multilayer structure polyethylene (outer layer)/foamed hygroscopic ionomer (absorbing layer) with 0–12% (wt/wt) sodium chloride/hygroscopic ionomer (sealing layer, inside) for fruit and vegetables packaging applications and polypropylene (PP)-based tarty used as control sample. In this study, trays containing 12 wt% of sodium chloride best maintained relative humidity inside tray for fresh tomatoes. Nevertheless, moisture loss of strawberries was greater than the moisture sorption rate by the tray. The authors claimed that the volume of water vapor absorbed by the tray during storage is directly proportional to the percentage of sodium chloride integrated into the trays matrix. Overall, the result concluded that the developed humidity-regulating trays have an effect on tomato and strawberries and are mean to extend the shelf life. Similar studies (Rux et al. 2015; Singh et al. 2010) reported with the varying amount (% on a weight basis) of sodium chloride as an active material in humidity-regulating trays for fresh produce packaging.

Polymeric films

The large variety of plastic materials and the diverse compositions available allow companies to adopt a food packaging solution and develop most appropriate to the particular needs of each product. Most polymeric films (polyethylene, polypropylene, polyvinyl chloride, polyethylene terephthalate) utilized in fresh produce packaging have a lower water vapor transmission rate relative to the transpiration rates of fresh produce. Similarly, for meat packaging films the amount of exuded water from the product is too high compared to the water vapor transmission rate of films. In such cases, moisture absorbing materials can be integrated throughout the package. By dispersing absorbing compound into the polymeric matrix (or by placing the humectants between two layers of a plastic film), moisture occurs in the package headspace and prevents moisture which permeates through the package from the external environment. This approach is applicable for the preparation of active films using moisture absorbing compounds by either solution-casting method (Chen et al. 2018) or melt extrusion (Choi and Lee 2013; Sängerlaub et al. 2018). Furthermore, the absorbers can be incorporated into the polymeric matrix via hot melt extrusion (DesiMax®SLF, Multisorb Technologies, USA), or integrated into foil and barrier laminates, such as with oriented polypropylene and metalized polyester to be develop into a pouch (SuperDryFoil™, Baltimore Innovations Ltd. UK; Maruto Sangyo Co., Ltd., Japan), and foil blister (Activ-Blister®, CSP Technologies, Inc., USA; Formpack®, Amcor Limited, USA). Recently, innovative moisture absorbing film Nor® Absorbit was developed by Nordenia International Germany. It is a flexible microwavable packaging film, which can absorb drip losses from packaged foods during microwave cooking (www.foodingredientsfirst.com).

Chen et al. (2018) developed moisture absorbing active packaging film based on polyvinyl alcohol (PVA). The result showed that the PVA film as active moisture absorbing film has the highest moisture absorbing capacity that is 29.2% at 80% relative humidity. Further, the film used for dried eel packaging confirmed that the quality index such as weight change, peroxide value, and thiobarbituric acid reactive substances (TBARS) value was changed more slowly during storage than that packed without PVA films. Lee and Lee (2016) tested moisture absorbing composite polymeric films from superabsorbent sodium polyacrylate particles and polyurethane (solvent-type). The water absorption percentage of polyurethane films incorporated with sodium polyacrylate was increased with reducing sodium polyacrylate particle size and with reducing ionic concentration in the bulk solution. Polyacrylic acid sodium salt applied in linear low density polyethylene (LLDPE) film as a moisture absorbing film was developed by Lee et al. (2014). The results indicated that an increased amount of polyacrylic acid sodium salt in moisture absorbing films showed a reduction in tensile strength, elongation at break, as well as tear strength of the developed film. 4% polyacrylic acid of incorporated in LLDPE films had high-moisture absorbency capacity compared to the other films with the different polyacrylic acid amount. A moisture-regulating film based on polylactic acid and polypropylene dispersed with calcium chloride (2–4 wt%) was developed by Sängerlaub et al. (2018) manufactured with biaxial stretching to induce the formation of cavities. Developed films absorbed reversibly up to 15 wt% water vapor at condition 75% relative humidity at 23 °C. Effective diffusion and effective sorption coefficients pronounce this water absorption performance.

Even though moisture absorbing films have been the commercial success, it has few drawbacks including the capacity and rate of moisture absorbing regulating polymeric films and laminates are considerably lower than descant-based moisture absorbing sachets (Choi and Lee 2013). Issues such as potential migration of moisture absorbing material from the film into food products are getting the attention of researchers. In addition, high amounts of absorbing materials are needed to assure dispersion all over the package, and major mass and activity losses can occur during the production (Gaikwad et al. 2018a).

Polymeric films for in-pack moisture control

Micro-perforated films

Barrier properties of polymeric films are a very important parameter to maintain gas and moisture composition inside the package. Films utilized in fresh produce have lower water vapor transmission rates as compared to transpiration rates of fresh produce, and hence, high humidity conditions occur in the packages, initiating moisture condensation, the growth of microbes, and hence short shelf life (Hussein et al. 2015; Bovi and Mahajan 2017). Perforated films that have micro-holes are penetrated through all the layers of the film. Depending on the size of holes, the film may be called micro- or macroperforated films (Yam 2010). Micro- or macroperforations are utilized to achieve higher gas and water vapor permeation through polymeric films. The perforations should be adjusted to get the equilibrium modified atmosphere in the package.

Moreover, besides improving gas and moisture transfer, perforations have been described to prevent in-package condensation. Perforation in polymer films is accomplished by various techniques such as laser perforation, cold or hot needle perforation, tube perforation and CO_2 laser (Hussein et al. 2015). Recently, Mistriotis et al. (2016) studied biodegradable micro-perforated polylactic acid films for cherry tomatoes and peaches packaging. Results showed that the water vapor permeability of poly lactic acid (PLA) films was very high compared to traditional orientated polypropylene (OPP) films which allow permeation of moisture from package to outside environment, and hence, no microbial growth was found on the tomato packed in perforated film compared to OPP film. Different polymers including oriented polypropylene (D'Aquino et al. 2016), biaxially oriented polypropylene (Kartal et al. 2012), low-density polyethylene (Dirim et al. 2004), and polyvinyl chloride (Simón et al. 2005) as a micro-perforated film for fresh produce packaging applications have been widely studied. Xtend® films (Tefen, Israel) are a commercial example of micro-perforated films. Almenar et al. (2009) examined the effects of micro-perforations in equilibrium modified atmosphere packaging for wild strawberries packaging below 10 °C. In comparison with non-perforated films, micro-perforated films using one and three perforations delivered suitable CO_2 and O_2 permeability when analyzed chemical and physical quality of strawberries. Results showed that the use of polyethylene terephthalate and polypropylene as packaging films having one and three micro-perforations with a diameter of 100 µm maintained the quality of wild strawberries through the generation of adequate permeability of gases and water. The 6-day shelf life was achieved for wild strawberries in micro-perforations package, though maintaining quality with the slight incidence of fungal decay and odor.

Common drawbacks of micro-perforated films are comparatively expensive, permit extra moisture from inside to outside and odor losses, and may permit for the ingress of microbes into sealed packs through wet handling conditions (Yam 2010).

Enhanced permeable films

Low oxygen and water molecules and high carbon dioxide permeability of generally used polymeric materials are not appropriate for preserving extremely respiring fruits, for example strawberries, garlic, tomatoes, mushrooms, and apple (Hussein et al. 2015). The solution to this is the development of high permeability toward water molecules compared to the commonly used plastic films, for example polypropylene or polyethylene (Bovi and Mahajan 2017). Using such packaging material, the level of condensed water in the package can be maintained throughout storage. Aharoni et al. (2007) tested a commercial Xtend® film which can effectively adjust gas composition as well as relative humidity inside the packages comprising various fresh produce. The cellulose-based NatureFlex™ polymeric film was developed by Innovia Films, Cumbria, UK. The permeability of water vapor of this film is 200 g m^{-2} day^{-1} at 25 °C and 75% RH, which is very highly compared to traditional polypropylene film (Sousa-Gallagher et al. 2013). Kim et al. (2016) prepared permeable composite films based on polypropylene and phase change material (octadecane) for packaging of cherry tomatoes. Films for water vapor and gases permeability were dependent on temperature. The water permeability of the polypropylene film increased from 0.5 to 11.1 g m^{-2} day^{-1}, while for the polypropylene–octadecane composite films it increased from 2.9 to 31.9 g m^{-2} day^{-1} with a temperature increase from 10 to 48 °C. Some researchers, for instance, Caleb et al. (2016), have used humidity windows instead of enhanced permeable films to cover the entire package in order to overcome this drawback. The use of enhanced permeable films is the only applicable packaging of fresh produce and not for other moist products such as raw meat.

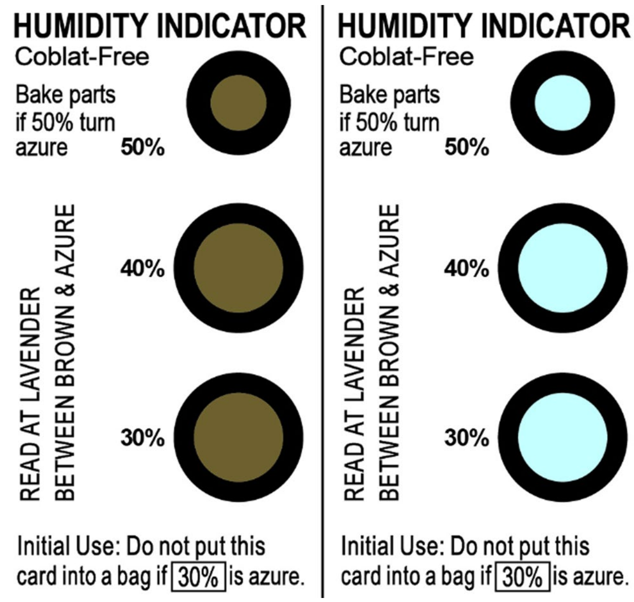

Fig. 5 Cobalt-free humidity indicator labels at a different relative humidity level

Trends in moisture absorbing packaging

Humidity indicator/sensor

High moisture inside the package can speed up the decomposition process in raw meats, dry powder such as sugar, milk powder, and salt lose textural and free-flowing properties if the moisture level is too high. Therefore, humidity indicators are desirable in the food industry for monitoring the quality, freshness, and shelf life of packaged food products (Esse and Saari 2008). An indicator is a material, which indicates the existence or lack of additional substance or the degree of reaction between two and more materials by means of a property change, mainly in color (Fig. 5) (Kim et al. 2017). In general, humidity indicators/sensors are prepared using electronic hygrometers based on capacitive or resistive structures that determine the change in conductivity of a polymeric or ceramic film as a function of moisture. Majority of colorimetric based humidity indicators are based on the inorganic salts, for example cobalt (II) chloride. However, such indicators have limitations in their operating circumstances and high cost (Zhang et al. 2013). Commercially, humidity indicators are well established such as cobalt chloride-free humidity indicator card (Ströbel GmbH, Germany), (Stream Peak International, Singapore); HUMITECTOR™ (Clariant Cargo & Device Protection, USA); HumiJudge (Kyodo Printing Co., Ltd., Japan) are available for monitoring relative humidity in the food package. The colored capacity indicators have been widely combined with desiccants, such as silica gels and calcium sulfate, to indicate the degree of water saturation of the desiccant as suitable substitutes for a humidity indicating cards. The common indicator is the "blue" anhydrous cobalt (II) chloride, which turns purple when it bonds to water molecules.

Further hydration results in the pink hexaaquacobalt (II) chloride complex. Due to potential toxicity, the blue indicating silica gel has slowly been replaced by the "orange," copper (II) chloride, which turns blue when reaching moisture adsorption capacity. Due to this reason, manufacturers are focusing on *cobalt chloride-free humidity indicator* for food packaging applications. Recently, Thompson et al. (2017) developed DryCard, a humidity indicator strip based on laminated on one side to PET and ethylene-vinyl acetate (EVA) polymer using a cobalt chloride, which changes color with altering relative humidity. Authors described that the DryCard™ has a dependable color response to humidity with fast response time to calculate approximately water activity. A humidity indicator was developed by Zhou (2013) using iridescent technology. A nanocrystalline cellulose film was produced by using a casting method to form a thick iridescent film in which chiral nematic texture was made by self-assembly of the rigid rod crystallites. The developed film's structure interacts with the electromagnetic field and indicates humidity percentage. The observed dry film color was stated blue–green. Upon contact to humidity or moisture, the color of film changes from blue–green to red–orange; to change the color in films, it required 2 s. Holst Center (Eindhoven, Netherlands) prepared a prototype of a flexible Radio-frequency identification (RFID) tag with integrated sensors which are able to monitor temperate and humidity and a resistive sensor proficient of perceiving the presence of amines (Smits et al. 2012). The RFID tag able to detect traces of trimethylamine gas is a sign of interest to assess the freshness of raw fish. The clear response to even as low concentrations as 1 ppm proposes that the tag may be well suitable for sensing the presence of trimethylamine in the headspace of the food package.

Antifogging films

Antifogging polymeric films prevent the formation of fog inside the food packages, for example fresh produce and raw meat packages. Antifogging films also let consumers see food in packages clearly (Ozdemir and Floros 2004). The antifogging property is essential for the packaging film when it is used for packaging of frozen products. The antifog films have been considered as a more eye-catching display for frozen food products (Hu et al. 2018). Antifogging materials are typically surface-active agents which consist of two parts: a hydrophilic head and a lipophilic tail; examples include glycerol fatty acid ester, polyglycerol fatty acid ester, a fatty acid ester of polyethylene glycol, alkyl ether of polyethylene glycol, ethoxylated alkyl phenol, sorbitan ester, ethoxylated sorbitan ester, and alkanol. When the antifogging agent incorporated in a polymer matrix, the antifogging agent migrates from the matrix to the film surface, reducing the interfacial tension between the polymer and the water drops. As a result, the water drops spread across the film surface.

Recently, Hu et al. (2018) developed antifogging multilayered film using acrylamide-modified chitosan and alginate aldehyde. The thickness-dependent antifogging property of the films initiates from the hydrophilic nature of the two polysaccharides, and the water drops absorbing ability of the films. Results state that the six-layer film displayed superior fog-resistant performance compared to three-layer film. The films can reinstate their original transparency and antifogging performance. Park et al. (2016) developed antifogging films derived from water-absorbing polymer (isosorbide epoxy resin). The antifogging ability was controlled by changing the film thickness. Introzzi et al. (2012) studied active LDPE films coated with pullulan as an antifogging coating. Pullan is an exopolysaccharide obtained from the yeast-like fungus *Aerobasidium pullulans.* The coated film showed effective in preventing fog on the surface of LDPE film as shown in Fig. 6. Authors claim that the pullulan coatings may be of significant importance as a superior, novel, and "green" alternative to conventional antifog agents in future food packaging applications. Other antifogging systems that prevent fog include polyglycerol fatty acid esters/polyethylene (Wei et al. 2017), hydroxypropylmethylcellulose and tannic acid/PLA (Zhang et al. 2018), silver nanoparticles, or grapefruit seed extract/ternary blend agar/alginate/collagen hydrogel films (Wang and Rhim 2015), agar, κ-carrageenan/konjac glucomannan/Cloisite® 30B clay (Rhim and Wang 2013), and silica/LDPE (Rosen-Kligvasser et al. 2013). Most of the polymeric films used in antifogging applications are made from polyethylene (PE), PET, EVA, polyvinyl chloride (PVC), and PP. Atmer™ antifog (Croda Polymer Additives, USA); Vistex® (FSI Coating Technologies, Inc., USA); WeeTect (WeeTect, Shanghai, China) are some examples of commercially available antifogging films for food packaging applications. The antifogging material has limitations in the polymer matrix when it uses packaging materials for food application. Important factors include its stability during film manufacturing and its impact on the other properties of the film, especially mechanical and barrier properties. Another key issue in the choice of the antifogging materials is its compatibility with the selected polymer matrix. Nevertheless, antifogging films for food packaging applications are expected to find more attention in the future.

Superabsorbent polymers (SAPs)

Superabsorbent polymers (SAPs), also commonly known as hydrogels or superporous hydrogels, denote one more remarkable family of desiccants. The SAP is in fact polyelectrolyte networks commonly known for their capability to absorb high amounts of water. One gram of the hydrogel can absorb more than 4000 g of water within 200 min, with half of this water being absorbed within the first 12 min (Delgado et al. 2009). Variety of monomers, typically acrylics, is used to prepare SAPs. Acrylic acid and its sodium or potassium salts, and acrylamide are commonly used in the industrial production of SAPs for packaging applications (Zohuriaan-Mehr and Kabiri 2008). Drip-absorbent sheets in meat packaging mostly comprise of two layers of a microporous polymer like polyethylene or polypropylene sandwiched with an SAP in the form of free-flowing granules (Biji et al. 2015). The superabsorbent polymer such as carboxymethyl cellulose and polyacrylate salts has solid attractions for moisture. Absorbing pads made from these polymers are usually placed under packaged fresh poultry, meat, and fish to absorb unattractive fluid exudates from the meat tissues. Large blankets or sheets are generally used for absorbing the melted ice during the distribution of chilled seafood.

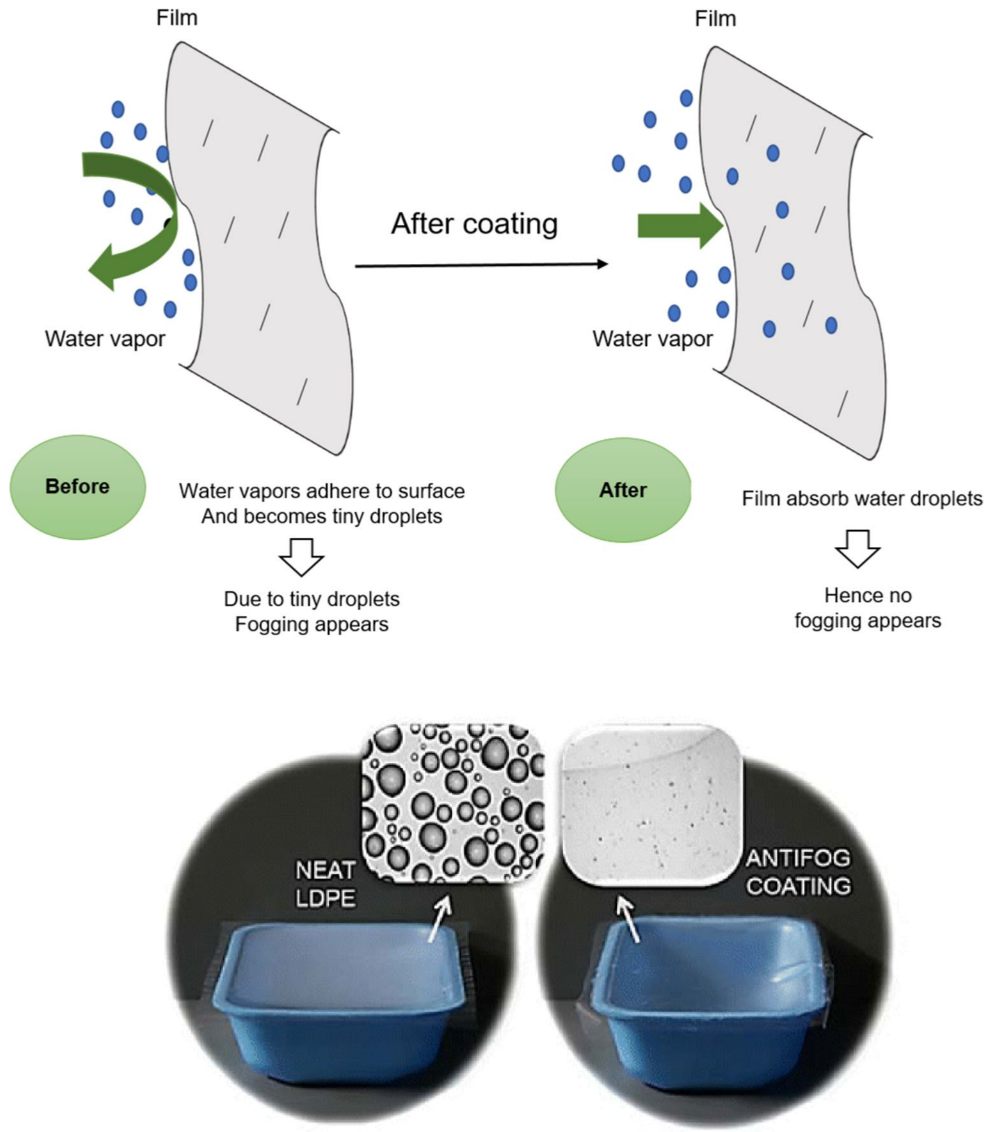

Fig. 6 Untreated LDPE and pullulan-coated antifogging film after removal from the refrigerator (7 days at 4 °C) at 20 °C. (Adapted and modified from Introzzi et al. 2012)

Recently, Mbuge et al. (2016) used SAP drying of maize and reduced aflatoxin contamination during the storage period. Kim et al. (2017) developed a pH indicator comprising moisture absorbing materials in the form of the pad for monitoring the freshness of chicken breast. The author used high water absorbance pad made with the three-layered structure of gauze/superabsorbent polymer (polyacrylamide)/gauze. Some patents have also been disclosed, exploring extensively on the development and properties of the SAPs based on the soy protein isolate (Damodaran and Hwang 1998). The inventors have stated that similar approaches can be used on other proteins such as leaf (*alfalfa*), microbial, animal proteins, and those recovered from food industries wastes.

Moisture sorption isotherm model

The relation in the moisture content and the water activity at a constant temperature is known as the moisture sorption isotherm (Yam 2010). Each food products have unique sorption isotherm at a constant temperature, and these statistics play a vital role in evaluating the ideal storage conditions for the food (Choi and Lee 2013). Although the knowledge of moisture sorption isotherms is broadly used to calculate the shelf life, it can also be used in evaluating other parameters such as design and optimization of packaging materials. The new methods of calculating the sorption isotherms are the electrochemical impedance spectroscopy and the infrared spectroscopy technique (Van der Zanden and Goossens 2004). Nonetheless, for food products, sorption isotherm can be measured in three different methods that is a gravimetric method, the manometric method, and hygrometric method (Iglesias and Chirife 1976). In the gravimetric method, the weight of the sample is measured until the samples reach an equilibrium stage. Several models can be found in the literature which analyzes the sorption behavior of the foods. Models which have been suggested and used for food products since decades are the Brunauer–Emmett–Teller (BET) equation, Guggenheim–Anderson–de Boer (GAB) model, Langmuir equation, Chen, Hasley, Henderson, Smith, Oswin, Lewicki, Iglesias–Chirife equation, and Peleg model as presented in Table 3 (Choi and Lee 2013). The GAB and BET models have been considered to be substantial and versatile sorption models (Siripatrawan and Jantawat 2006). Though the BET model has been used for numerous food products, the GAB model has a benefit over the BET model as its strong theoretical background, and it can be considered as an upgraded version of Langmuir and BET theories (Delgado et al. 2009). The second, an important factor of using a GAB model, is that it can be used for a wider range of water activities that is 0–0.95, unlike BET model which can only show best results when water activity is less than 0.60 (Siripatrawan and Jantawat 2006). Equilibrium sorption isotherms model used for the seasoned laver packed in moisture absorbing film by Choi and Lee (2013). Results disclosed that the calculating the BET monolayer value was utilized to determine the water activity that could provide the maximum shelf life for the dried product. The monolayer value was calculated from the BET equation derived from the isotherm data of the seasoned laver below a water activity value of 0.35. The model also provided data that allowed for the characterization of the seasoned laver.

Other studies that used various moisture sorption isotherms include GAB for fish gelatin films (Hazaveh et al. 2015), bovine gelatin films (Nafchi et al. 2014), chitosan–glycerol films (Monte et al. 2018), chitosan bio-based and intelligent films (Yoshida et al. 2014), and soy protein isolate/poly(vinyl alcohol)/glycerol blend films (Su et al. 2010). Further, Langmuir isotherm model for hydroxypropyl methylcellulose-based nanocomposite films (Klangmuang and Sothornvit 2016), BET model for gelatin films containing nanoencapsulated tea polyphenols (Liu et al. 2017). The models that are commonly used highly most in food products are BET and GAB models. The GAB model underestimates the moisture content values at high water activity levels (aw > 0.93). The discrepancy underlines two facts: This type of model is inappropriate for a high humidity range, and the saturated salt solution method does not deliver appropriate information to get a comprehensive sorption curve (Choi and Lee 2013).

Table 3 Moisture sorption isotherm mathematical models

Model	Equations
Henderson	$\mathrm{Ln}\,[-\ln(1-a_w)] = n \ln M_{eq} + \ln K$
Chen	$\mathrm{Ln}\,(-\ln a_w) = K - aM_{eq}$
Halsey	$A_w = \exp\,(-a/M_{eq})$
GAB	$M_{eq} = C(K)\,(a_w)\,(Wm)/(1-Ka_w)\,(1-Ka_w+Cka_w)$
BET	$A_w/M_{eq}\,(1-a_w) = 1/M_mC + a_w\,(C-1/M_mC)$

A_w is water activity, M_{eq} is equilibrium moisture content, M_m is monolayer moisture content

a is a constant which represents the slope of the straight line between the $-\ln A_w$ and M_{eq}

n, K, and C are constants

Food packaging applications

Fruits and vegetables

One of the key issues with packaged fruits and vegetables is condensation, leading to additional free water in the package. The relative humidity in the package is promoted by respiration and transpiration process of the fresh produce, in addition to the water vapor permeability of the used packaging material (Bovi and Mahajan 2017). Moisture condensation dynamic in packaging system containing fresh produce during storage period is presented in Fig. 7. Most of the polymeric materials utilized in the packaging of fresh produce have lower water vapor permeability compared to the transpiration rates of fresh produce. As a result, most water vapor that evaporates from the fresh produce does not escape through the packaging material and stay within the package; in these circumstances, minor temperature fluctuations may result in condensation in the package, leading to an acceleration of microbial growth and further spoilage of produce (Linke and Geyer 2013). The relative humidity inside the package can be controlled by the use of moisture absorbers in the package (Bovi and Mahajan 2017). Various research studies based on the use of moisture absorbers for food packaging applications are presented in Table 4. Murmu and Mishra (2018) used coarse silica gel as a moisture absorber in combination with MAP technology for guava fruits. The fruits stored with silica gel showed minor physiological weight loss, higher retention of total phenol content, and ascorbic acid content after 1 month of storage period compared to the control. Wang et al. (2017) used sodium carbonate-based sachets and sodium carbonate with calcium hydroxide and sodium carbonate incorporated in the cotton pad for shiitake mushrooms packaging. Results showed that the sachet combined with sodium carbonate and the

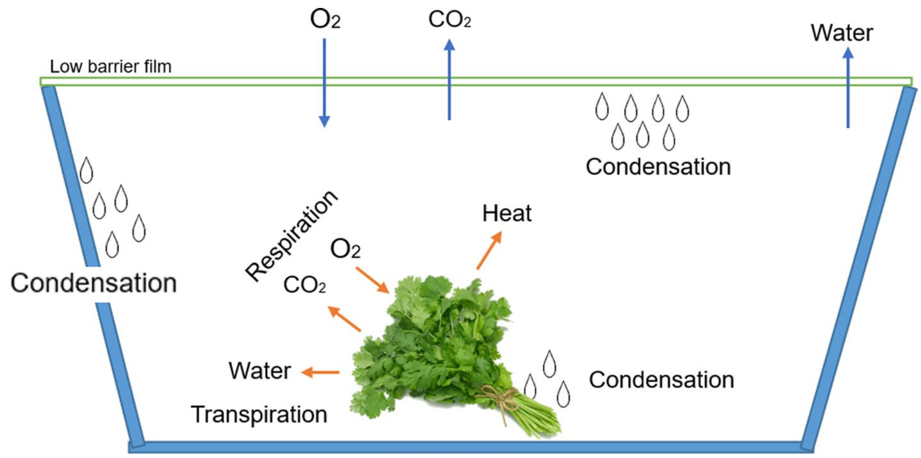

Fig. 7 Moisture condensation dynamic in package containing fresh produce during storage. (Adapted and modified from Bovi and Mahajan 2017)

superabsorbent polymer was effective in the quality preservation of mushrooms. Superabsorbent polymer was studied by An (2016) in master packaging system for preservation of fresh shiitake mushrooms in the distribution process. The packaging system with superabsorbent polymer improved mushroom preservation and mainly reduced decay during supply chain and storage compared to the control sample. Other packaging systems that used for different fresh produce which absorb condensed water include drip-absorbent pads for fresh-cut cantaloupe (Wilson 2017), humectant salt for wild pomegranate (Sharma and Thakur 2016), sodium carbonate for shiitake mushrooms (Wang et al. 2015), calcium sulfate for breba fruits (Villalobos et al. 2015), calcium chloride, sorbitol, sodium hexametaphosphate for mushroom (Ya et al. 2015), silica gel for fresh chilies (Zhao et al. 2014), silica gel crystals for green bell pepper (Singh et al. 2014), silica gel, calcium chloride, sorbitol for button mushroom (Shahraki et al. 2013), sodium chloride for avocado (Illeperuma and Nikapitiya 2006), and sorbitol for broccoli (DeEll Jr. et al. 2006).

The challenge of using moisture absorber in fresh produce is continually finding a balance between reducing moisture condensation and keeping produce weight loss as less as possible. While choosing the most appropriate approach for moisture control, it is essential to know the physiological characteristics of the fresh produce. Additionally, the application of predictive mathematical modeling can be important tools for choosing the most appropriate packaging system (Bovi and Mahajan 2017). The drawback is that such mathematical models are typically product specific because of fresh produce dissimilarities in transpiration and respiration process, along with different suggested humidity levels.

Meat, fish, and poultry

Raw meat naturally contains a high amount of water (more than 75%). Due to the oxidation process, excessive cellular damage follows in meat and water can saturate in the packaging container and hence leak during distribution and storage (Singh et al. 2018c). The exuding liquids (water, blood, or other fluids) are a sign of unhygienic meat from most customer's perception. Moreover, it supports the microbial growth, thus reducing stability and shelf life of the packaged meat (Ren et al. 2018). To overcome such issues in meat packaging, absorbent pads are commonly used in the meat industry to absorb the exudates and create an attractive package. Recently, Ren et al. (2018) studied *N-halamine* antimicrobial compound coated on absorbent pads for raw beef packaging applications. Findings state that the absorbent pads coated with *N-halamine* reduced the levels of total aerobic bacteria, that is, *Pseudomonas* spp., and bacteria to under the detection limit. Further, *N-halamine*-coated pads were capable of decreasing microbial loads in packed beef samples by 1 log CFU g^{-1} on average. A sorbent polymer (polyacrylamide) is used as a moisture absorber for the development of pH indicator by Kim et al. (2017) for monitoring the freshness of chicken breast. In the study, a superabsorbent pad was used to avoid direct contact of the used dye with the chicken and to increase the color change sensitivity of indicator. Results state that developed pH indicator comprising high-moisture absorbing materials demonstrated the excellent possibility for monitoring the freshness of various meat products as well as chicken breast. Fernández et al. (2009) prepared absorbent pads incorporated with silver nanoparticles (4–9 nm) achieved through silver nitrate. Since traditional absorbent pads are commonly used in the commercial market as part of packaging structures for meat preservation, the prepared nanosilver-based absorbing pads were verified in poultry meat, resulting in a 40% decline of the total aerobic microbial (TAM) growth, while the LAB was unobserved (Fernández et al. 2009). Other packaging systems include polyvinyl chloride overwrap and absorbent pad for preserving the quality of chicken breast (Charles et al. 2006).

In meat packaging, the selection of moisture absorber on the basis of type, size, and capacity is very important to

Table 4 Research studies on the use of moisture absorbers in food packaging applications

Moisture absorbing material	Polymer matrix/packaging form	Food application	References
Dri-loc® AC	Polyethylene-based pad	Raw beef	Ren et al. (2018)
Poly(vinyl alcohol)	Poly(vinyl alcohol) film	Dried eel	Chen et al. (2018)
Silica gel	Sachet	Guava	Murmu and Mishra (2018)
Silica gel	Drip-absorbent pads	*Fresh-cut cantaloupe*	Wilson (2017)
Cellulose/fructose	Polyethylene-based pad	Strawberries	Bovi et al. (2018)
Hydroxy propyl methyl cellulose, carboxy methyl cellulose	Coating on food	Jaggery cubes	Chand and Kumar (2018)
Polyacrylate	Tyvek film-based sachet	Shiitake mushrooms.	Wang et al. (2017)
Polyvinyl alcohol	Polyvinyl alcohol-based pH indicator	Raw chicken breast	Kim et al. (2017)
Sodium salt/hygroscopic ionomer	Linear low-density polyethylene-based tray	Strawberries and tomatoes	Rux et al. (2016)
Superabsorbent sodium polyacrylate	Polyurethane films	–	Lee and Lee (2016)
Desiccants	PET/aluminum foil/polyethylene film	Moist food	Haraguchi (2016)
Superabsorbent polymer	Sachet	Shiitake mushrooms	An (2016)
Humectant salt	Aluminum laminated pouch	Wild pomegranate	Sharma and Thakur (2016)
2-(Dimethylamino)ethyl methacrylate	Antifogging coating	–	Zhao et al. (2016)
Polyacrylate/sodium salt	Powder in a porous tea bag	Dry maize	Mbuge et al. (2016)
Sodium carbonate, sodium glycinate	Food-grade agar film	Shiitake mushrooms	Wang et al. (2015)
Calcium sulfate	Polypropylene punnets	Breba fruit	Villalobos et al. (2015)
Calcium chloride, sorbitol, sodium hexametaphosphate		Mushroom	Ya et al. (2015)
Sodium chloride	Thermoformed multilayer trays: PP/foamed and stretched, PP-NaCl/EVOH/PE	Mushrooms	Rux et al. (2015)
Polyacrylic acid partial sodium salt	Linear low-density polyethylene film	–	Lee et al. (2014)
Silica gel	Paper-based pad	Fresh chilies	Zhao et al. (2014)
Silica gel crystals	Polymer-based sachet	Green bell pepper	Singh et al. (2014)
Synthesized attapulgite with acrylamide	Linear low-density polyethylene film	Dried-seasoned laver	Choi and Lee (2013)
Silica gel, calcium chloride, sorbitol	–	Button mushroom	Shahraki et al. (2013)
Pullulan	Pullulan coating on LDPE	–	Introzzi et al. (2012)
Calcium chloride, sorbitol	–	Oyster mushrooms	Azevedo et al. (2011)
Sodium chloride	PP/foamed and stretched PP-NaCl/EVOH/PE	Mushrooms	Singh et al. (2010)
Calcium carbonate	Unsaturated polyester resin	–	Kia (2010)
Potassium chloride, calcium chloride, sorbitol, bentonite	Powder in trays/bags in the package	Mushrooms	Mahajan et al. (2008)
Desiccants	Micro-perforated polyethylene-based sachet, Humidipak®)	Cheese	Pantaleão et al. (2007)
Sodium chloride	Poly-coated paper pouch	Avocado	Illeperuma and Nikapitiya (2006)
Calcium sulfate	–	Strawberries	Changrue et al. (2006)
Sorbitol	LDPE bags	Broccoli	DeEll Jr. et al. (2006)
Sorbitol	Cassava starch film	–	Mali et al. (2005)
N, O-carboxymethyl	Chitosan/gelatin blend film	–	Zhang et al. (2005)
Hylon VII (*Amylose starch*)	Chitosan-based film	–	Cervera et al. (2004)
Zein powder	Zein-based film	–	Wang and Padua (2004)
Polyvinyl alcohol	Chitosan–polyvinyl alcohol blend film		Srinivasa et al. (2003)
Sorbitol, silica gel	Polyvinyl chloride, LDPE	Pleurotus mushrooms	Villaescusa and Gil (2003)

PP polypropylene, *NaCl* sodium chloride, *EVOH* ethylene vinyl alcohol, *PE* polyethylene, *LDPE* low density polyethylene avoid adverse effects in meat; such as, the absence of oxygen on the side of meat that is in contact with the moisture absorber can produce a color change in the product from red to brown. Limitation of pads in the meat pack is the saturated exudates from the pad may generate unwanted odors and support the microbial growth. Thus, decreasing microbial loads in absorbent pads and use of antimicrobial with the absorbent pad is essential for successful food quality and safety during food packaging and storage.

Dry food products

Even though dry food such as powders, such as pasta, cookies, biscuits and milk powder, and instant coffee powder, contain very low moisture that is around 2–3% water, the water vapor permeates through the packaging material from outside to inside package unfavorable to the quality of such food product. Moisture affects the shelf life of food including crystallization, stickiness, and texture. The rate of crystallization rises as moisture increases, therefore limiting the shelf life (Duckworth 1981). Permeation of high amount of water molecule from package wall may also help oxidation of fat. The use of high-moisture barrier film or active barrier film, that is, use of moisture absorber in packaging film for moisture sensitive food, is recommended (Gaikwad et al. 2018a). Choi and Lee (2013) developed LDPE film incorporated with synthesized attapulgite with acrylamide as a moisture absorbing film for packaging of dry seasoned laver. The 4% attapulgite with acrylamide LDPE film confirmed a moisture absorbency of 44.59% at a water activity of 0.71. However, the mechanical properties of the developed film such as tensile strength and elongation of breaks were decreased with increasing the amount of moisture absorber into film matrix. The absorbing film successfully maintained crispiness of dry seasoned laver that is 0.66 N on day 30. A multifunctional packaging film prepared by Chen et al. (2018) with functions of moisture absorbing as well as antioxidant properties based on polyvinyl alcohol and green tea extract. Results showed that the neat PVA film showed 29.25% moisture sorption; further, this film utilized for packaging of dried eel and it is found that the film containing 2% green tea extract showed the best quality protective efficiency to prevent the dried eel from absorbing moisture and oxidizing of lipid. A superabsorbent polymer is used for dry maize and reduction in aflatoxin contamination during storage period by Mbuge et al. (2016) under various temperatures and drying times. Results demonstrate that temperature and the amount of superabsorbent polymer influenced the drying rate and aflatoxin contamination of maize. Moreover, it is shown that superabsorbent polymer had a good capability for grain drying and can be used iteratively.

Research needs and prospect

A promising future is expectable for moisture absorbing packaging system especially in the form of films and pads for food preservation since they are suitable to the food safety approach, which includes an enhanced level of food safety and transparency to customers. The use of moisture absorbers in the form of sachets, trays, films, and pads are well accepted, in the commercial market. Nevertheless, the use of moisture absorbers in polymer-based packaging material continues to attract researchers from industries as well as from academia. New research relies on the focus of the food and packaging industries. The technologies involving combine antimicrobial emitting sachets and absorbent pads will be continuing to improve as new active packaging technology in meat industries. The natural-based active moisture absorbers have been widely exploited by the scientific community all over the world due to growing demands for less artificial substance or chemical in food or food packaging. The application of bio-based and biodegradable packaging materials such as PLA and PVA is also advised as environmentally friendly substitutes for the carrier, sachet, and packaging materials. Complications in the processing of moisture absorbing films present a challenge. The trends of using natural-based absorbing agents have increased from past few years. Nevertheless, natural materials are unstable at the high processing temperatures commonly used in polymer melt extrusion; therefore, it is challenging for scientists to integrate such materials into film matrices. New committed migration tests and mass transfer modeling tools must be established for migration analysis of active materials from package to food since the present methods for traditional packaging might not be appropriately adapted to active systems. Possible toxic migrants are a technical challenge since the active material must be compatible with the packaging material. The standard level of migration is set by regulating agencies, such as the US Food and Drug Administration (FDA) and the European Union (EU). Evaluating migration indicates the development of committed migration tests and mass transfer modeling tools.

A humidity indicator and sensor that indicates the level of moisture in the package could act as both an active and intelligent package element. The reception of new moisture absorbers will rest on their safety for direct food contact and their incapacity to leach toxic substances into the food and beverages. Overall, researchers are more concerned about the absorption of unwanted by-products as well as the moisture absorbance capacity of these systems each in vitro or in vivo. When actual food quality is tested, even though their physicochemical qualities are generally evaluated, the findings lack data on the sensory impact led by the use of absorbent pads and sachets. The use of multilayer active oxygen absorbing films will continue to be of attention because of the demanding permissible requirements for high barrier food packaging applications. This will serve to drive not only packaging innovation but also a future study into absorbing agents. Nanomaterials are predictable to play a major role in moisture absorbing packaging, taking into account all other safety concerns and filling the currently prevailing gaps in knowledge.

Conclusion

Moisture absorber containing active packaging is a favorable future direction for the development of high water activity food packaging. It is confirmed that the use of moisture absorbing packaging could extend the shelf life of fresh produce as well as meat products. Thus, the parallel application of both inorganic and organic based in films form not only fulfills consumer demands for replacement of artificial preservatives and polymers but also delivers stronger protective effects from excess moisture in the fresh meat and fresh produce. At the time of choosing the best appropriate material or form of packaging for moisture regulation, it is very important to understand the physiological characteristics of the food product. Moreover, the use of predictive mathematical modeling can be valuable tools for choosing the most appropriate packaging system. Nevertheless, the growth and application of this type of packaging will depend on the acceptance and cost-effectiveness for the food processing industry and consumers.

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