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REVIEW ARTICLE

Role of oxygen absorbers in food as packaging material, their characterization and applications

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Abstract To preserve the environment and to prevent the damage caused by packaging materials, the development of biodegradable, organic, and nano-active films for packaging is progressively being accentuated. As the demand for getting fresh and preservative-free food is increasing, an improved level of clarity and stability for consumers about the packaging is required. Presently, oxygen scavengers are used in the form of films, sachets, powders, or as part of the packaging material itself along with other means of preservation such as the use of chemicals, reduced water activity, pH, multilayer composite material, and or vacuum or modified packaging. Today's current demand increases their incorporation directly into the packaging material rather than being a part of the food itself. The present review, therefore, is based on the availability of types of natural sources of oxygen scavenging systems like antioxidants, and nano iron, and their possible scope of use in the food packaging industry.

Keywords Cobalt neodecanoate · Migrants · Natural scavengers · Nano iron · Oxygen-absorbers · Simulants

Abbreviations

OS	Oxygen absorbers
PET	Polyethylene terephthalate
pph	Pound per hour
ROS	Reactive oxygen species
MAP	Modified atmosphere packaging
TT	Time temperature
g/dm^2	Gram square decimetre
PP	Poly propylene
O_2/m^2	Oxygen per meter square
cc	Cubic centimetre
cm^3	Centimetre cube

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Introduction

Stability and safety of fresh and processed food products have always been considered an important parameter of food preservation. Furthermore, increased demand of them for the foods having fresh quality led industries to look for better-advanced methods of food processing and clean label packaging. Oxidation of food causes undesirable flavor in food leading to pigment discoloration and microbial contamination (Jensen et al. 2003). One of the smartest ways of maintaining the quality of fresh and highly perishable food products is by using oxygen absorbers. These absorbers preserves the food against oxidative damage from within a packed environment and provides better storage with improved food security (Cichello 2015; Gaikwad et al. 2018). This is done by increasing the activeness of the packaging materials and thus, is also considered one of the most prominent sources of active packaging techniques. Active packaging actively controls the environment inside the package either by the use of additives, preservatives, antioxidants, etc. to control the events taking place inside the package (Lopez-Cervantez et al. 2014). Certain advanced methods of food preservation, material science, biotechnology, and bioinformatics along with active packaging will further help in maintaining the nutritional and sensorial attributes of food (Floros et al. 2000). The packaging of the absorber usually consists of paper and polyethylene. These packages allow oxygen and moisture to enter but does not allow the iron powder to leak out. The present study thus focuses on the utilization, characteristics behaviour and application of oxygen absorbers also known as deoxidizers in the food packaging industry.

Methods of scavenging technology

Food products like baked goods, confectionery products, meat, and fish products, nuts, coffee, tea powder, etc. can be prevented from getting deteriorated with an increased shelf-life when packed with oxygen absorbers. These absorbers can be used as scavenging material along with PET bottles, lids, plastic trays, films, and crown cork for different types of food products including fermented and unfermented beverages. Thus overall contributed to prevent the free oxygen from contaminating the inner package environment (Cruz et al. 2012). Types of materials that can be used as scavengers are:

(1) Enzymes like glucose oxidase or ethanol oxidase, catalase, hydroxyethyl cellulose, polyvinyl alcohol. Glucose oxidase is oxidised to gluconic acid and hydrogen peroxide as:

$$2C_6H_{12}O_7 + 2O_2 + 2H_2O_2 \rightarrow 2C_6H_{12}O_7 + 2H_2O_2$$

Hydrogen peroxide so formed is further been catalysed in the presence of catalase so as to prevent unacceptable loss of nutrients (Roberta 2020). Catalase plays an important role in protecting the cell from oxidative damage by reactive oxygen species (ROS). It catalyses the decomposition of hydrogen peroxide to water and oxygen.

$$2H_2O_2 + \text{ catalase} \rightarrow 2H_2O + O_2$$

(2) Oxidizable chemical species like iron, ascorbic acid, tocopherol, catechol, sulphite, and nylon are used. Iron based scavengers are the most widely used metallic scavenging agents used for packed food products along with increased efficiency, low price and faster rate of oxidation. In general, the shelf life of a product has been observed to be increased from three-four days to up to 14 days and more (Gaikwad and Lee 2017). These absorbers can beneficially be used with non-respiring product like meat, pastries, nuts, cheese, snacks, dry flour etc. (Broody et al. 2001).

The first patent for the removal of oxygen in metallic packaging was developed in Finland in the year 1938. It used iron, zinc and manganese as a source of scavenging material. And the first major commercial oxygen scavenger was introduced in Japan in the year 1970 by Mitsubishi Gas and Chemical Company and was made thereafter available in the United States also during the same year which was sold by the name Ageless (Cooksey 2010). After this, scavengers were looked upon as an important part of food packaging material such that CSIRO has also contributed by making for it a single source of package scavengers.

Charles et al (2003) used commercial iron-based oxygen scavenger to develop a model that could be easily used in further simulations of active MAP of other respiring products and evaluated the potential interest of using oxygen absorbers in traditional pouches. This could help to minimize the number of needed experimental trials to predict the size, the type, the capacity, the absorption rate of the required absorber.

(3) Photosensitive polymers, form the base of the organic (non-metallic) packaging material. In case of packets in the form of porous sachet, pyrogallic acid was firstly used and a patent for the same has also been granted (Yam 2009).

(4) Now-a- days activated carbon, powdered iron along with calcium hydroxide and sodium chloride powder are also being used because of their tendency to adsorb oxygen. Other salts like potassium and sodium sulphite can also be used. Certain non-ferrous variants such as ascorbates with sodium hydrogen carbonate are also in use. As far as oxygen scavengers are concerned they contain ferrous carbonate and chemical oxidizing systems like metaxylene adiamide and a metal halide catalyst like cobalt – salt catalyst (Dawson and Stephon 2004). In case of inorganic absorbers, film theory was used to model absorption units.

The above mentioned scavengers are based on self-adhesive labels, devices or loose sachets that can be used in the packaging material with the food. Another way of using them is by developing a monolayer or multilayer materials or reactive closure liners for bottles and jars, pouches, lid stock, bag-in-box, retort, and HPP (Rooney 2005). In enclosed packaging, these help to remove the levels of oxygen in a package and thus maintain and extend the product's shelf life.

It is assumed that a thin boundary layer made of gas and liquid film separates the gas and liquid phases. Mass transfer within the films occur by molecular diffusion. The rate of diffusion is defined by the absorption coefficients and is dependent on the concentration of the solute in the gas at the interface, and in the liquid. (Hall 2012). By using vacuum method, palladium was used to check the percent retention of the residual oxygen in the headspace of the packaging material made up of polyethylene terepathalate, aluminium oxide coated polyethylene terepathalate, oriented PP and poly lactic acid (Yildirim et al. 2015). Palladium at a thickness of about 0.7 and 3.4 nm along with silicon oxide has further contributed to increase the scavenging property of the packaging material. Polyethylene terepathalate was also successfully used with 3-layer oxygen scavenging film to ensure the shelf-life of fresh cut apples for 15 days at 8 °C by Maio et al. (2014).

Mechanism of scavenging

On removal of the absorber from its protective packaging, moisture from within the surroundings start permeating inside the sachet containing iron particles to convert it in to iron oxide thereby reducing the surrounding oxygen below 0.01% (Miltz and Perry 2005). The iron oxide so formed is not a component of an oxygen absorber. As the rusting is initiated, iron and oxygen together form iron oxide and an average relative humidity of 65% is maintained. In general, iron oxidises in the presence of moisture or lewis acids like ferric chloride, sodium chloride and or aluminium chloride takes place to form ferric oxides under low humidity's and therefore acts as catalysts (Cruz et al. 2012) (Fig. 1). Different materials with scavenging activity are:

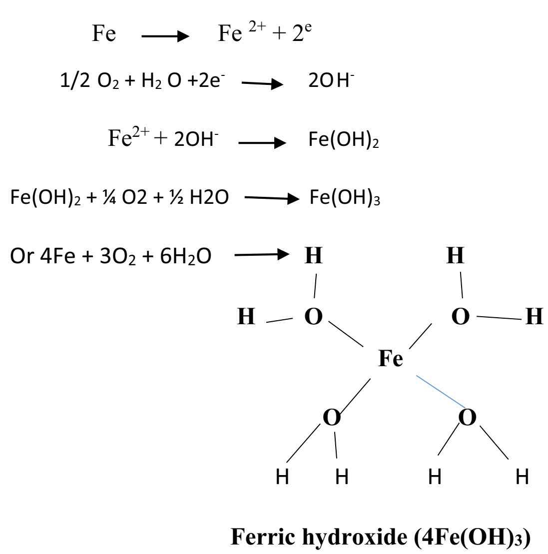


Fig. 1 Chemical reaction for rusting process of ferrous based oxygen absorber (Cichello 2015)

Iron powder containing polymer films

As per Cruz et al. (2006), such mechanism was found to be useful in lowering the growth of microorganisms like yeast, moulds or coliforms. For example, in case of lasagna pasta microbial growth can be controlled at a temperature of 10 °C during storage under vacuum technology by keeping them under high oxygen barrier bags. Increased temperature led to increased rate of absorption of oxygen in sausages packaged with iron powder containing polymer films that showed a scavenging capacity of 33 cm^3 O_2/m^2 film in 4 days (Gibis and Rieblinger 2011).

In case of milk powders alkanes, alkenes, aldehydes, and ketones are majorly responsible for lipid peroxidation leading to onset of foreign odors. To check the stability of iron-containing scavenging material in meat products, it was immersed in water or 3% acetic acid for a specific period of time and temperature. The samples were packed with filter paper that was pre-saturated with the help of a simulant and placed between the glass plates. After this, the packaged material is kept inside the oven for specific TT and is then checked for specific and overall migration (Dainelli et al. 2008). The inorganic oxygen scavengers segment is the largest and is projected to continue till 2026.

Improvements and contributions in active packaging

Baele et al 2020 have studied the effect of oxygen on the quality of two cured meat products. These were sliced ham luncheon sausage and sliced pork liver pate that tend to spoil due to lipid oxidation, protein degradation, and microbial spoilage. They packaged the products in two different packaging materials, one with high permeability and another with low permeability to oxygen. Both the packages were used inside the lidding film with and without an oxygen scavenging sticker with an overall capacity of 50-ml O_2. The samples were also kept under three different conditions i.e. dark storage, followed by illumination by fluorescent tubes at 1000 lx for 2880 min, and dark storage followed by illumination by LED sources for 2880 min. They concluded that scavenger does not completely eliminate all oxygen, but rather engages with the packaging product itself and its microbial flora for utilization of permeating oxygen. In addition, for oxygen-sensitive products, scavengers should be considered as an add on to high barrier packages for removing residual oxygen, rather than improvising a disappointed packaging material.

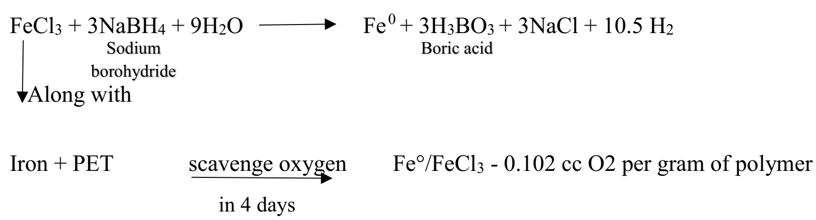
Another study by Zaitoon et al 2021 have focused on the use of gaseous and volatile compounds as active packaging component for agri-food products. They emphasised the controlled use of encapsulation technique along with various volatiles in to polymer matrix. Gases like CO_2, ClO_2, SO_2, ethylene, 1-methylcyclopropene and volatiles like ethanol, ethyl formate, essential oils can enhance the storage stability of active packaging systems.

Photosensitive dyes

For dry food products photosensitive dyes also called as photon dyes are used to increase the rate of reaction of the OS (oxygen scavenger) films. This photosensitive film was activated with the help of UV light to excite the dye molecules to senisitize the oxygen molecule so that it can be diffused and can be converted in to singlet state in the film. The reaction mechanism can be shown as:

$$\text{Photon} + \text{Dye} \rightarrow \text{Dye}^{*}(\text{activated with photon showing excitation})$$

anhydrous environment (Foltynowicz et al. 2017). Nano-iron showed better oxygen scavenging activity both in presence of moisture and anhydrous environment (Foltynowicz et al. 2014). Formation of nano-tubes containing mineral carbon embedded within plastic film containing natural oils extracted from thyme and oregano tend to possess antimicrobial activity and helps in preventing microbial degradation, oxidation and moisture absorption. Kaolinite and bentonite have been recommended by the European Food Safety Authority (EFSA) as non-nanoform species. Usually iron powder exhibits particle diameter in the range of 10 to 30 μm whereas nanoparticles vary in the size range of 1–100 nm. Use of nanoparticles provides better scope as scavenging particles due to quantum size effects, increased surface area to volume ratio that increases their efficiency of iron powder to react and ability to match up with the surface properties via molecular styling (Sun et al. 2006). Yan et al. 2013 has reported that use of iron oxides like goethite or hematite at increased temperatures or electric current are prominent sources for commercializing zero valent iron nanoparticles.



$$\text{Dye}^{*} + \text{oxygen} \rightarrow \text{Oxygen}^{*}$$

$$\text{Oxygen}^{*} + \text{Acceptor} \rightarrow \text{Acceptor oxide}$$

$$\text{Oxygen}^{*} \rightarrow \text{Oxygen}$$

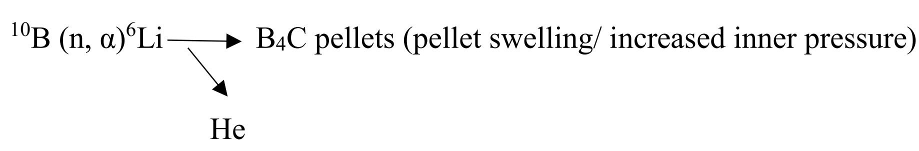
Nano-iron

Utilization of nano-iron metal and nano iron oxide (zero valent iron particles), based on iron-containing kaolinite or bentonite formed by the depletion of an iron salt in presence of sodium borohydride showed better scavenging activity as compared to particles of micrometer size both in presence of moisture and

In case of nano- iron along with polymer the scavenging capacity of nano-iron has been observed to be 300 cm^3 of oxygen in 5–6 days. Variable polymers like silicon matrix, nylon 6,6, PE and or PVA films showed 100 percent oxygen scavenging capacity within a period of 3–6 days.

Variety of absorber materials

A conventional absorber material is B_4C (Boron carbide). Its acceptability is because of its high neutron absorption ability, low cost, ease of fabrication, and low radioactivity after irradiation. Natural boron contains about 20% ^{10}B, and the remainder ^{11}B. The main reaction involves (Donomae and Maeda 2012).



High thermal conductivity prevents the absorber pins from reaching excessive temperatures. A high absorbing material melting point means that the material can be used at high temperatures and will remain stable. Different processing techniques like aseptic processing, retorting, microwave processing, ultra -high temperature, high intensity pulse light and non-thermal techniques like high pressure processing have been used to check the stability of these films with respect to physical and chemical properties. Of these HPP has been found to be a better method as foods can tolerate a pressure up to 400 MPa for 300–1200 s. Above this pressure a change in physical properties of the packaging material has been observed.

Sodium chloride acts as a catalyst and assist in the process of oxidation. It has been observed that oxidation of one gram of iron can lead to the removal of 300 cm^3 of oxygen under standard conditions. Oxygen absorbers can be used independently to modify the composition of the internal atmosphere within the food packages. In a study on ripened Gouada cheese effectiveness in prolonging the shelf-life of cheese as compared to that of vacuum packaging and modified atmosphere packaging was analysed by Panfil-Kuncewicz et al. (2015). They stored the samples for 30, 60 and 90 days and, the counts of coliform bacteria, yeasts and molds were determined. They analysed that oxygen absorbers were effective in extending the shelf-life of ripened cheese as vacuum and modified atmosphere packaging. Different materials like plastics and paper can be used as packaging material for the sachets.

Now-a-days oxygen scavenging system with reactive hydrocarbon polymers doped with transition metals were also been reported to be used (Coquellet et al. 2007). For e.g. Shelfplus O_2 2600 is a polymer: polyethylene/ploypropylene based oxygen scavenger, having tendency to absorb oxygen in the head section and the product itself. It is generally used for the rigid packaging materials, flexible films and cap seals. Apart from this, various reactive hydrocarbon species used were: poly (m-xylylene adipamide), commonly available as MXD6, cobalt neodecanoate and polybutadiene as poly 1,2 and 1,4- butadiene. Poly (m-xylylene adipamide) increases the oxygen barrier properties (OTR) of the packaging material without the use of additivess. Various antioxidants from 1,4- polybutadiene are to be removed before they are used as oxygen scavenging materials. Cryovac has developed a clear lidstock oxygen scavenging co extruded film containing a oxidizable polymer, a photo-initiator and a catalyst. The polymer job is to react and bind with the oxygen. The coating of polymer in the headspace of a packaging material provides stability to the food product that are prone to rancidity by oxidative reactions. In totality, the polymer prevents the food from getting deteriorated due to off flavour and off-odor development. The photo-initator role is to provide energy to initiate the reaction and the catalyst helps to reduce the activation rate of the overall reaction (Fig. 2).

Polo et al. (2021) have developed a double function active packaging material containing integrated polybutadiene (PB) as an oxygen scavenger along with integrated peanut aroma for wrapping of nuts in an LDPE packaging material. The modified packaging material was compared with the control based on the mechanical, structural, optical and thermal properties. They concluded that the oxygen scavenging capacity and the aroma retention capacity of the packaging material has been improved without the use of a metal catalyst. Overall it helped to prevent lipid oxidation in nuts even after 6 days of storage under normal conditions. Sangerlaub et al. (2021) have tested an oxygen scavenger system based on vacuum-deposited palladium (Pd) on PET film. Here, Pd catalyzes the reaction of headspace oxygen, within the food packages along with hydrogen. In addition, silicon oxide (SiO_x) layer was applied to the films before Pd build-up to improve the substrate surface condition. In order to check the oxygen-scavenging activity, Pd-metalized films were placed into an airtight cell. These cells were flushed with a gas mixture containing 95 vol.-% N and 5 vol.-% H. Set amounts of oxygen were also inserted into the cells and different cover films were used to check the amount of absorbed oxygen and Pd-metalized film. The films used were polyethylene, polyethylene with EVAC, and microporous PE-HD and in one, no cover film was used at all. The amount of oxygen absorbed in g/dm^2 within different cover films were 39, 113, 1003, and 1016 and the oxygen permeance g/dm^2 bar was observed to be 7, 79, and 263 whereas in no cover film no result was obtained. According to them, the oxygen-scavenging rate is firmly reliable on the ratio of hydrogen: oxygen and OS rate increases with a decrease in H: O. Thus, in food packaging an adjustment in the levels of hydrogen in MAP to residual oxygen present in packaging is necessary.

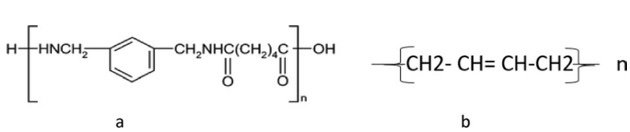


Fig. 2 Structure of **a** poly (m-xylylene adipamide) and **b** 1,4- polybutadiene

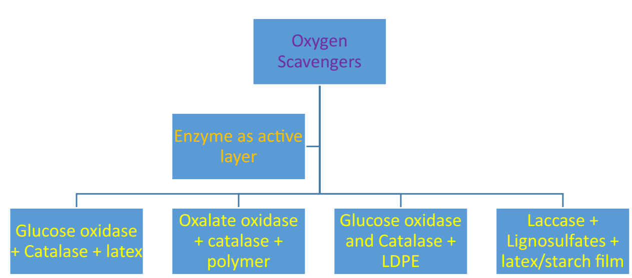


Fig. 3 Different OS with enzymes in the active layer

In another study, the oxygen scavenging film was significantly found to extend the shelf-life of peach puree based on the variation in the color quality of puree throughout storage (Skrypec et al. 2021) (Fig. 3). Promsorn and Harnkarnsujarit in 2022 have also prepared oxygen scavenging bio-based plastics to control oxygen contents in food packaging.

Johansson et al. (2011) has stated that the activity of the glucose oxidase along with catalase has decreased from 1.4 µmol O2/min to 0.1 µmol O2/min in 40 h due to the ageing of the enzymes. They also reported the scavenging rate with varying clay content as 95 pph (pound per hour)—600 µmol O2/min. g of substrate, and 33 pph—450 µmol O2/min. g of substrate. As far as LDPE is concerned the best scavenging capacity was found to be 7.6 ± 1.0 l/m^2 (Anderson et al. 2002). Enzycoat is the novel oxygen scavenging system used for functional coatings in packaging films, reported by Nordic Innovation Centre as a successful coating powder mixed with polymer and coated in the inner layer (Marria 2015).

Natural oxygen scavenger

Certain natural compounds like pyrogallol (phenolic compound present in amla) showed the highest oxygen scavenging capacity of 51.81 mL O_2/g with a scavenging rate of 6.48 mL O_2/g a day when used in an equivalent ratio of 1:1 along with sodium carbonate (Gaikwad and Lee 2016).

Leghaemoglobin a red-colored pigment extracted from the root nodules of leguminous plants such as soybean acts as oxygen scavenger and is a well-known nitrogen fixative source.

Certain natural antioxidant substances such as polyphenols or anthocyanidins from grape-pomace and hop plants are shown to have a correlation between the antioxidant activity and the oxygen scavenging properties (Anonymous 2014). In 2014 the use of a Co(II) complex (an original oxygen scavenger) $Co(L\text{-}Thr)_2(OH_2)_2$ on the basis of natural compounds (threonine) was made. They were used in polar polymer films based on polyvinyl alcohol (Damaj et al.). The active films were prepared by the water casting technique for an efficient industrial process. In the year 1938, a British patent used iron, zinc, and manganese to scavenge oxygen from canned foods.

Organic based oxygen scavenging

Kassim et al. (2018) used methyl ethyl ketoxime (MEKO) and erythorbic acid to investigate the effect of organic oxygen scavengers on the performance of pyrrole as a corrosion inhibitor (EA). They discovered that adding erythorbic acid (EA) to a saline solution containing 100 ppm of pyrrole enhanced the inhibitory efficacy to around 67%, compared to MEKO, with 59% efficiency. Due to many impacts of efficient corrosion inhibition, pyrrole in combination with oxygen scavengers has been discovered to improve the efficiency of inhibitive actions (Ridwan et al. 2012).

Microbial immobilization

Microorganisms and their source in today's day can be used as an antimicrobial agent, for the extraction of pectin, acids and enzymes, etc. the In case of OS as well due to moistening of headspace surface chances of yeast grown can be suppressed by using an aerobic type of microorganisms capable of absorbing oxygen. Cell immobilization by using alginate, agar, and gelatin has been successfully implemented and recyclability, safety, material compatibility, and production costs were also controlled. An eco-friendly OS film using hydroxyethyl cellulose and PVA to entrap two different kinds of microorganisms was used by Altieri et al. (2004). The film was optimized to prolong the viability of the microorganisms and to promote the capability of the film to remove oxygen from the headspace of the package. Enzymes like glucose –oxidase, laccase, and oxalate oxidase that were used in a dispersion coating formulation applied onto a food-packaging board were extracted from different microbial sources. Laccase enzyme was produced from Trametes versicolor (TvL), Myceliophthora thermophila (MtL), and Rhus vernicifera (RvL) (Kristin 2013). Different microorganisms including actinomycetes, bacteria, fungi, protozoa, microalgae, and yeast, produces variety of antioxidant compounds, i.e., carotenoids, polyphenols, vitamins, and sterol, etc. and thus possess wider scavenging capacity (Rani et al. 2021).

Market dynamics and impact of Covid-19 on oxygen scavenging market

Currently oxygen scavengers (non-volatile sulfites and bisulfites) are being used in the form of water treatment processes for the preparation of fermented and unfermented beverages, paper and pulp treatment, gas and chemical industry generally to prevent corrosion problems. Covid-19 lead to shift in the demand patterns and variation in the choice of the consumers. Due to poor supply chain industries have to bear revenue losses and decreased capital expenditure. At the same time following proper hygiene practices at workplaces, government fiscal support and better supply chain facilities to boost revenue and stabilize growth were a challenge. Increasing demand for fresh quality packaged food lead to the utilization of oxygen scavengers inside sealed packaging. These scavengers can maintain original food quality, prevent the growth of aerobic pathogens and food spoilage microorganismsm, change in color and flavor due to rancidity of polyunsaturated fats and oils, degradation and, oxidation of vitamins especially Vit. A, C, and E, and non-enzymatic browning fruits and some**.** The product remains healthier and stable for longer time without the use of additive thus driving the growth of oxygen scavenging market globally. Even Ahmed et al 2022 have highlighted the significance of active packaging systems on to the quality of product in their review study. They have also discussed the relationship of active packaging with current limitation in technologies, consumer behaviour and legislation.

Health concern and consumer acceptance

The main source of public worry, which has resulted in a slower rate of growth of oxygen scavengers, is the possibility of leaking within the packing material. Cough, body pains, chest tightness, and pneumoconiosis can occur if a powdered iron sachet is leaking. As a result, regulation of scavenging systems in terms of packaging and application should be considered in order to protect the safety, stability, and quality of the food and the consumers. Certain regulatory programmes for the use of active substances in food, such as the food additive petition and the GRAS notification scheme, must be followed. A new directive, EC Regulation 450/2009, was also introduced for clearer clarity of the usage of such materials.

Benefits and industrial applications

Inorganic iron-based scavengers are predicted to expand at an annual rate of 6% from 2.2 billion USD in 2021 to 2.9 billion USD by 2026. Along with a CAGR of 5.5% in the coming future, particularly for flexible and rigid packaging materials. Oxygen absorption agents serves a variety of purposes, including inhibiting microbial development, reducing the amount of residual gas in the package's headspace, and preventing oxidation–reduction reactions in the food. They can also be used as an alternative to vacuum and gas cleansing technologies (Johnson and Decker 2015). Without being a part of the meal, oxygen can be easily removed from a food material's interior (Fig. 4).

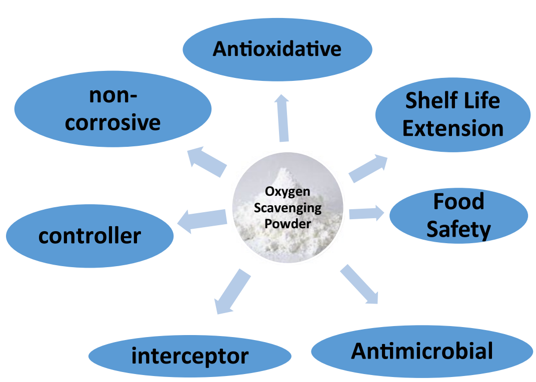


Fig. 4 Benefits of oxygen scavenger (OS) as film forming material

Today with the rise in population and changing lifestyles there is an equal demand for packaged food products, rising disposable incomes, and overall convenience associated with packaged products. Various factors such as increased privatization, married couples with double income, moving away from home town, staying alone, and a rise in nuclear families are boosting the demand for packaged food, which in turn has the positive rise in the demand for oxygen scavengers. They are currently used for meat packaging, bakery products, juice packaging and milk products (Table. 1). For most of the products, a mixture of iron powder, sodium and activated carbon (charcoal) has proven quite effective. Iron powder serves as the primary component, while sodium acts as an activator, causing iron particles to rust, effectively reducing the oxygen level in the surrounding atmosphere to approximately 0.01% when used appropriately. Activated carbon acts as gas absorbent thereby further preserves the products from unsavory odors. In general, there are two types of oxygen absorbers used for food storage. These are B" absorbers and "D" absorbers. B absorbers requires moisture from the food they are packed with to perform their function. For e.g., dehydrated fruit that hasn't been dried until stiff. The absorbers are mostly suited for dry product packaging as they have sufficient moisture required for their activation. The shelf life of B-absorber is up to one year whereas D-absorbers last maximum for 6 months. The absorbing capacity of B-absorber is quite slow as they have to first absorb moisture from the food product before they absorb oxygen whereas D-absorber generally show activation within 1200–1800s.

Limitations and potential risks

Although such kind of packaging system will be a boon to the food and packaging industry still there are certain limitation which are based on the oxygen absorbing capacity of the absorbers through the package wall. This leads to increased permeation and accumulate in the headspace of the package. Onset of saturation level also increases the water activity of food that give possible chance for microbial growth resulting in of-flavors, taste and, color. Therefore, food safety and security becomes a question in such kind of packaging systems as well. Such issues are well checked by keeping control on certain parameters. These are:

Table 1 Properties and availability of oxygen absorbers in different forms

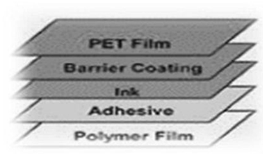
Types of absorbers	Regulations	Properties	Types of absorbers	Food uses	References
 Sachets and or packets	Moisture regulation	Barrier properties	Meals ready to eat (MRE), Oxy-Guard, Ageless, Strip-pax, Amosorb, minipax, Mylar Bags (20 cc), O Sorb, Oxysorb	Ideal for condiments, sauces, and seasonings	Washburn (2011)
 Coatings	Ethylene removal system	Superior seal integrity		Iron powder prevents infestation and bitterness	Mexis and Kontominas, (2010)
 Films	Carbon dioxide scavenging	Single use		Dry fruits, fresh tomatoes, PET bottles	
	Anonymous (2021), Abreu et al. (2011)				
 Card, adhesive labels, closure liner or concentrate, pouches, wraps	Antimicrobial active packaging	Easy to handle		Ascorbic acid, iron powder prevent rancidity and flavor change	Berenzon and Saguy (1998), Vermerin et al. (2003)
	Anti-oxidative	Economic		Pharmaceuticals, fresh and precooked pasta and noodles, flour and grain items like Breads, cookies, cakes, pastries, candies and confectioneries	
	Oxygen scavenging	Environmental friendly		Iron powder prevents fungal and mold infestation	
	Thermally insulated	As an alternative in multilayer film and paper packages		Silica-ascorbic acid prevents moisture absorption and the growth of microorganisms	

Table 1 (continued)

Types of absorbers	Regulations	Properties	Types of absorbers	Food uses	References
	Improved shelf-life	Increased sale		Ideal for beef jerky, processed, smoked, and cured meats cheeses, dairy products, pepperoni, dried nuts, and vitamins, Iron powder with catalyst and or mineral carbon nanotubes prevents the loss of nutritional value, discoloration, loss of taste, odor, microbial growth, and degradation	
		Reduced shrinkage			
		Vit. C retention			
		simple and effective			
		maintains food quality, aroma, flavour, texture			

- Allowing the oxygen polymers used in the packaging film or sachet to scavenge slowly to prevent the oxygen from the headspace of the package, as well oxygen migrating from external environment. Films with high oxygen barrier properties should be used to prevent loss of its ability to trap oxygen.
- To provide some strong barrier agents for oxygen for packages with oxygen scavenger to prevent the external environmental conditions to interfere with the internal conditions. In general, 20 mL/m^2 a day atmospheric oxygen is allowed inside these packages.
- The weight of the scavenging material must be considered according to the size of the packaging material used.
- In case of flexible packaging material proper sealing should be done to prevent the void air spaces in the sealed portion to prevent the external air to react to disturb the inner environment.
- Migration test and mass transfer modelling tool must be introduced for appropriateness of the use of such packaging material. For chemical reaction moisture must be supplied by the food itself or by inner conditions within the package (Nerin 2010).
- Metallic iron needs humid conditions for its scavenging activity as they become inert in dry or water sensitive products (Foltynowicz and Rikhie 2020). Therefore, certain amount of moisture to activate the oxygen absorption reaction of some commercial sachets is required (Gabriele 1999).
- *Clostridium botulinium* type E an anaerobic pathogen proliferative bacteria can survive in an oxygen scavenging environment therefore a combination of other preventive technique should be used with it (Rooney 1995).
- Sachets use is limited to solid foods and cannot be used with liquid foods so that the package should not block the path of the absorber any packaging that may have sections to entrap oxygen. Absorbers can be used with food having low oil content.
- Sachets cannot be reused (Eggimann 2011).
- Optimization of the pack is required in accordance with the shelf life and free space inside the pack.
- Oxygen scavengers such as hydrazine and iron oxides are considered harmful to human health. For e.g., hydrazine can irritate the eyes, nose, and throat and cause dizziness, headache, nausea, pulmonary edema, seizures, and coma. It has been suspected as a carcinogen by the U.S FDA. And iron oxide can cause fever, chest tightness, cough, and pneumoconiosis. The health issues related to oxygen scavengers have led to the development and implementation of various action plans against handling harmful chemicals.

Conclusion

In the case of both fresh and processed foods, oxygen packaging techniques will have a substantial impact on how food is packed and kept. Without the use of additional artificial additives, oxygen scavengers utilised in specialised packaging systems help to maintain freshness and avoid rancidity. Because these scavengers do not react with air oxygen until package construction, they have a lot of promise to be one of the best packaging materials for oxygen-sensitive foods. Furthermore, consumers can be given a clear picture of food safety. For the promotion of the unambiguous use of these scavengers in natural form, motivation at the level of food producers, consumers, and retailers is required, as well as industrialists who will introduce the material in various forms.

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Authors' contributions The study is solely reviewed and written by me. The review paper has not been submitted anywhere for publication. As corresponding author, I confirm that the manuscript has been read and approved for submission by me. I hope that you find the manuscript suitable for publication and look forward for hearing from you in due course. The main findings of this paper highlights the suitability of using oxygen absorbers as a sole functional ingredient for preventing spoilage in food products and their use should be maximized. The psychological myth with respect to absorbers limits their use in different food products and thus should be promoted. During recent years nothing much has been discussed to promote the use of these absorbers in different forms in food and thus there is a need to show their positive effect for better utility and for lesser use of preservatives. Also there are lot of questions arising on the plastic packaging materials and their effect on food, due to the package-flavor migration issues that questions food stability and security. And thus newness by way of packaging is required that provide stability to the food and oxygen absorbers are the way out for that.

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Declarations

Conflict of interest The study holds no conflict of interest.

Consent to participate As only single author is involved so no Consent to participate is required.

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