Chapter 2
Polymer-Based Bionanocomposites for Future Packaging Materials

Sarat K. Swain, Niladri Sarkar, Bhagyashree Patra and Gyanaranjan Sahoo

Abstract Packaging technology is mainly dealing with the safety storage and hygienic handling of daily needs and undergoes in continuous modification with time as per the choice of the consumers. With the ever-increasing market race, psychological aspect of the consumer behavior is also reflected in the packaging technology. For easy production and low cost of synthetic plastic materials, it has won the prime interest in packaging field. But, environmental issues lead the system to run behind the fabrication of eco-friendly bionanocomposites with incorporation of nanomaterials in renewable, biodegradable polymers in order to obtain bionanocomposites with improved fire retardant, oxygen barrier, thermal and mechanical properties. This chapter focusses some important basics of polymer-based bionanocomposites for packaging applications. The mechanical, fare retardant, thermal and gas barrier properties are improved substantially with incorporation of nanomaterials with biopolymers. Herein, the commercial, physiological and safety aspects of packaging materials are also discussed for the promotion of polymer-based nanocomposite as a future smart material for packaging products.

Keywords Packaging · Psychological aspect · Plastics · Bionanocomposites Fire retardant · Oxygen barrier

2.1 Introduction

The term packaging is not a word of today's generation; it has taken birth in ancient. In ancient age, packages were made of natural materials like baskets of reeds, botal bags, wooden boxes, pottery vases, wooden barrels, woven bags,

S. K. Swain (✉) · N. Sarkar · B. Patra
Department of Chemistry, Veer Surendra Sai University of Technology, Sambalpur 768018, Odisha, India
e-mail: swainsk2@yahoo.co.in

G. Sahoo
Department of Chemistry, Veer Surendra Sai University of Technology, Burla, Sambalpur 768018, Odisha, India

M. Jawaid and S.K. Swain (eds.), *Bionanocomposites for Packaging Applications*,
https://doi.org/10.1007/978-3-319-67319-6_2

ceramic amphorae, etc. In current age, when someone mentions packaging, what is the first thing that comes to mind? Possibly, brightly colored cereal boxes designed to entice children, or may be the impenetrable plastic cage. Packaging, itself represents a technology dealing with the distribution of products from industry to market zone to consumer's house. Packaging technology is all about the process of designing, evaluating and production of packages. Packaging plays a pivotal role in marketing, safety storage and hygienic handling of daily needs (Coles et al. 2003). The application of packaging is not limited to a single sectors. It spreads its wings to several sectors like bulk chemical packaging, medical-device packaging, retail-food packaging, pharmaceutical packaging, military packaging and so on. As it is related with the safety storage, it is also categorized by the layer of function. In many countries, it is fully integrated into business, government, institutional, industrial and personal use. In marketing, packaging is used to add more importance to motivate the consumers by notifying the product details, including composition and branding context, called package labeling. Package labeling is any written, electronic and graphic communication on the package. Packaging is used for convenience and information transmission. On the other hand, package labels communicate how to use, transport, recycle or dispose of package or product. The package and package labeling are highly used by the marketers to encourage potential buyers to purchase the product. Many types of symbols for package labeling are nationally and internationally standardized. For consumer packaging, symbol exists for product certification (such as TUV and FCC marks), trademarks, proof of purchase, etc. Recently, a great effort has been done on motivational research, color testing and physiological manipulation of the daily products to draw the consumer's attention to new package. Based on the results of this research, past experience, and the current and anticipated decisions of competitors, the marketer will initially determine the primary role of the package relative to the product. The things that we really need to address that what is the purpose of packaging and how this technology is evolving over the year with respect to the consumer's needs.

2.1.1 The Main Aspect of Product Packaging

The main purpose of packaging is to transport the products from the manufacturing industry to the customer's house with its original form, i.e., keeping its freshness, form, function and composition throughout the transit. The most important aspect essentially followed by the marketers during the designing of packages is that the transfer of product must be maximally efficient in terms of time and cost.

Packaging has its own brand value and it is maintained by the industrialists. As we know, coke is a worldwide recognized brand; industrialist will not prefer to make a huge change in their brand. Minor changes can be made without modifying the original look so that it could be recognizable with its brand success. Therefore, one can easily say that packaging has created brand recognition.

2.1.2 Safety Maintenance in Product Packaging

Depending on the type of product, package designing firstly ensures the protection of products from external factors like vibration, compression, electrostatic discharge, mechanical shock, temperature, etc. In case of food items, packaging protects and preserves food items purchased by consumers. It retains product freshness and prevents risk of cross-contamination with other food items, pesticides and harmful pathogens. During processing and transportation, foods can be exposed to chemical, biological and physical risks. Hence, proper packaging can only save the food and drinking items from damage by blocking the exposure of hazardous chemicals, sunlight, gases and moistures. Permeation is a critical factor in package designing. Some packages contain desiccants or oxygen absorbency to extend shelf life. Modified atmospheres or controlled atmospheres are also maintained in some food packages. Keeping the contents clean, fresh, sterile and safe for the intended shelf life is a primary function. Packaging materials made of glass and metal shield foods from pathogens and chemicals.

2.1.3 Commercialization of Product Through Packaging

The second purpose of packaging is related to the commercialization of product and its brand visibility. Being a marketer everyone has the desire to be on the top as compared to their other competitors. Everyone provides the best product in their category and wants to make best selling product. In order to achieve the dream, creative food packaging with information transmission is a necessary one.

The last purpose of packaging is related to its security. On shelling product without packaging, there is a high probability that the retailer does not give the right amount to the customer and saves some part for himself. Packaging reduces the security risk during shipment. For better security, packages are made up with improved temper resistant material and also bearing some features to indicate tampering. Packages can be engineered to reduce the risks of package pilferage.

The choice of color in package designing is also play an important role in commercialization of products. Our brain has different thoughts regarding different colors. For example, products with white cover convey safety, purity and simplicity whereas; black color keeps the secrecy, and the complexity in thoughts. In the same way, a light sky blue reflects the playful mood, while dark navy color is considered as much professional. If you think of baby, then the things should be colorful. It is important to study the target demographic before deciding on a color scheme for your product packaging.

There are several reasons for doing packaging such as safety, brand visibility, theft prevention, etc. Packages can have features that add convenience in distribution, handling, stacking, display, sale, opening, reclosing, use, dispensing, reuse, recycling and ease of disposal. The packaging technology we have today has evolved over the time to better perform the function under the specified aspects. With the development of new marketers and ever-increasing market race, advertisement of the product through attractive and unique packages has opened up a new era in packaging technology. As the paper worker revealed that one-third of consumer has taken up their decision on packaging to purchase their product, marketers are devoted to make the product packages distinguishable and unique in look from other available products. For example, Captain Morgans has recently created a new product, "Cannon blast" in a container shaped like a cannon ball which has grabbed a huge attention due to relevant designing of product package with the name of the product. It is also eye catching and highly distinct from what many of its competitors offer.

2.2 Psychological Aspect of Product Packaging

In packaging technology, manipulation of consumer behavior is one of the main criteria for marketing of the products. It relates with the thought and action process of the consumer, i.e., ultimate end users. The whole thinking process of consumer is related to several factors, such as money, time, energy to select, use and disposal of product goods, services and anything else that satisfies the customer's personal desire. Therefore, marketers should have knowledge of consumer's desire, so that a proper product designing and development, marketing communication, pricing and placement in distribution channels could be established. Although the physiologist, Ivan Pavlov had demonstrated his theory in 1870s by the name of "theory of conditioning." But with the progress of time, Pavlov theory has entered into the market place to analyze the consumer's buying behaviors (Pachauri 2001). According to this theory, consumer is represented as subject, whereas product package is represented as stimuli. In the store, packaging acts as the gate way of product. Therefore, product packages are heavily cultured to influence the consumer's buying behavior or subject's response. This interrelated phenomenon is represented in Fig. 2.1. The first way of purchase along the decision-making pathway is to recognize the need by consumer. In second stage, they actively verified the product look and product information available across various channels and comparing their needs with product information. In the final stage, they decide to purchase the product that satisfies their needs. According to classical conditioning theory, product packaging directly influences a consumer's perception of the product. Consumer's perception is directly related to their assessment that what they receive (quality) versus what they give (price). Consumer has a high tendency to compare directly the price with quality. A normal expectation that comes into mind before buying a high-price product that it should offer a high quality. Throughout the decision-making process, they are searching for the cues that satisfy their own expectations. Consumers are generally interested to spend their time and involving themselves into the whole process of ensuring the best choice under the given circumstances. Spending time and involvement in product purchasing are the

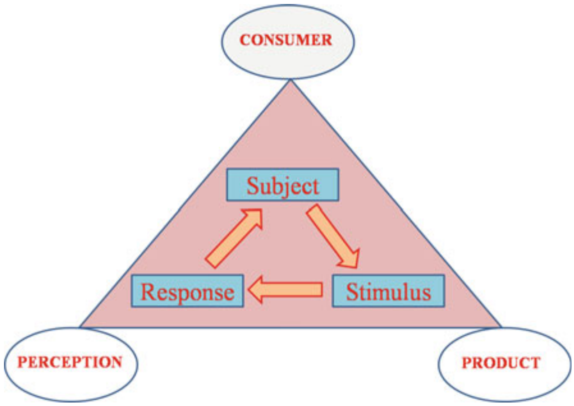

Fig. 2.1 Ian Pavlov's stimulus response theory explains the consumer buying behavior

different emotion. For product purchasing, spending time is necessary, whereas involvement is an optional one. The degree of involvement is related to consumer's psychological, personal and social context. Before making any decision to buy the product, a consumer has gone through several mental stages and these are attention, comprehension, attitude and intent. A simplified modeling of consumer's path of purchases is schematized in Fig. 2.2a, b. Social media such as reference groups, family, colleagues, friends, online review forums have a great impact on the attitude and perception of consumer's buying behavior. Each of these inputs acts as signal to affect the buying decision. Among all input signals, only certain signals have strong impact on the consumer's attitude that are either appeal emotionally or strengthen their beliefs. Various aspects that affect the consumer's perceptions during the progress through different stages of decision-making pathway can be explored through "Tarben Hansens conceptual frame-work" and shown in Fig. 2.3.

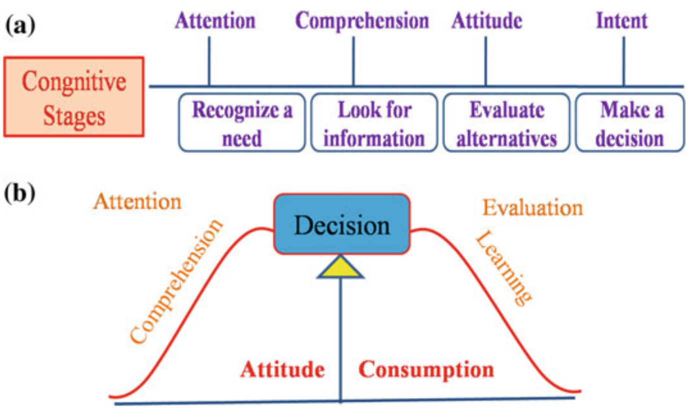

Fig. 2.2 **a** Different cognitive stages of decision-making pathway of consumers; **b** A simplified modeling of consumer's path to purchase

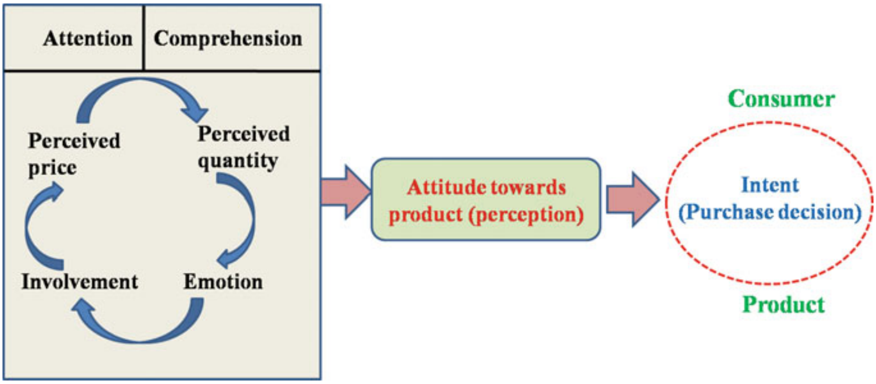

Fig. 2.3 The conceptual framework is adapted from perspectives on consumer decision making: An integrated approach

Sometimes, consumers are not gone through the well-known framework of mental stages and instantly take the decision, known as impulsive decisions. As in case of impulsive buying, consumers appear to skip most stages of decision-making pathway, cognitively they are responding to visceral cues from product packaging. This type of purchasing behavior is observed for 70% purchases of supermarkets. Hence, no doubt in the display of product and product information through packages is of great importance in product marketing.

2.3 Revolution in Packaging

As we discussed earlier, the main role of packaging is to protect or safety storage of products. Depending on the type of product, packaging has been introduced in several ways. Product information is related with the content, storage condition and nutrition value of the product. For food packaging, i.e., packaging related with food and drinking items, packaging continues to protect the items once they are in the home and can extend the period when they are safe to eat and of their best. For the packaging of vegetable items, freshness of the items should be guaranteed. Therefore, green vegetables such as root vegetables and cucumbers are restored in the packages that do not allow the loss of water. This helps to keep them fresh for a longer period of time. Recently, as packaging material, plastic products have won the primary interest and the use of plastics for food packaging is increasing day by day. This fact is attributed by the low cost of production. With the progress of time, a huge research effort has been dedicated to the formulation of new plastic materials with improved thermal, mechanical and fire retardant properties. The oxygen barrier performance is another important property that influences the characteristics of packaging materials. When we make our first choice “plastic,” unknowingly we bring some problems to our society. No doubt, the petroleum-based plastic materials are light in weight and therefore, easy to handle. They can be made of various colors and shapes. But these are non-biodegradable in nature and lead to the unwanted pollution to our nearby surroundings. That is why, we are moving toward the age of "green revolution" by replacing commercial polymers with biopolymers.

2.4 Environmental Aspect of Product Packaging

To avoid the environmental pollution, the use of different biodegradable synthetic polymers, particularly aliphatic polyesters, such as poly (ethylene succinate) (PES) (Oishi et al. 2006), poly (L-lactide) (PLA) (Wee et al. 2006), poly (p-dioxanone) (PPDO) (Sabino et al. 2000), poly (butylenesuccinate) (PBS) (Carroccio et al. 2004), poly (€-caprolactone) (PCL) (Kai et al. 2006) are used with nanoparticles to fabricate bionanocomposites with superior properties. But the source of synthetic polymer is limited. Polymers obtained from the natural resources are of great interest in packaging industry due to their low cost, renewability, ease of surface modification and high compatibility with inorganic fillers. Starch, chitin, chitosan, cellulose, lignin and proteins are the name of few widely used biopolymers. But they have some drawbacks like high hydrophilicity, poor processability and low-mechanical strength. The integrating combination of biopolymers and nano fillers has recently grabbed the light as nano fillers and its efficiency to overcome these drawbacks. Manufacturing of starch nanocomposites has become of growing interest as a promising option toward enhancing the mechanical and barrier property.

2.5 Role of Starch in Packaging Application

Among different biopolymers, starch is a highly abundant polysaccharides and biodegradable in nature. It is composed of two structural units and these are amylose (linear) and amylopectin (branched) (Fig. 2.4). Each unit consists with the repetition

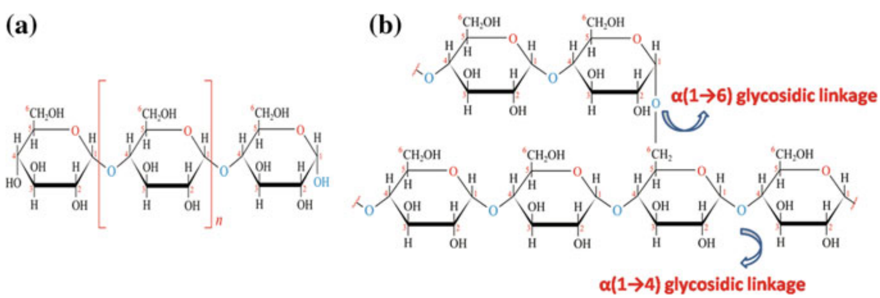

Fig. 2.4 **a** Amylose and **b** amylopectin: Two structural units of starch

of 1,4-α-D-glucopyranosyl units. Starch is stored as granules in plants for future food source. Starch has lot of uses such as thickener, water binder, emulsion stabilizer, gelling agent, coating sizing in paper, textile, adhesives, adsorbents, encapsulates and so many. Starch is a suitable option to substitute petroleum-based plastics for the fabrication of short-term packaging materials. The high sensitivity of starch toward moisture has limited their practical application. To introduce biodegradability into synthetic polymers, starch is blended with various polymers like polyethylene (PE), low-density polyethylene (LDPE) (Psomiadou et al. 1997), polystyrene (PS), poly (ethylene-vinyl alcohol) (EVA) and poly (ethylene-co-acrylic acid) (EAA). But the attempt fails to show the biodegradable response.

Therefore, starch is allowed to blend with various biodegradable synthetic polymers like poly (lactic acids) (PLA) (Zhang and Sun 2004), poly (hydroxybutyrate-co-hydroxyvalerate) (PHBV) (Willett and Shogren 2002; Rosa et al. 2004b), polycaprolactone (PCL) (Rosa et al. 2004a), poly (glycolic acids) (PGA) (Kong et al. 2011) and PHB (Rosa et al. 2004b). Starch has also been blended with PCL, PHB (Godbole et al. 2003) and PHBV (Avella and Errico 2000) showing a dramatic change in their properties. We have studied the oxygen permeability and flame retardant of Polymethylmethacrylate/starch composite in our earlier report (Kisku and Swain 2012).

2.6 Polymer Nanocomposites: An Alternative to Non-Biodegradable Plastics

Due to high surface area to volume ratio, unique physical and chemical properties, nanoparticles are widely used with polymers to fabricate polymer nanocomposites with improved properties. High surface area is a critical factor for the performance of catalysis and electrochemical performance in fuel cells and batteries. Nanocomposites exhibit excellent flexibility, low density and easy processability in connection with the high strength, rigidity and heat resistance. The enhancement was observed on mechanical properties, thermal stability, gas barrier properties, electric properties, even on biodegradation rates. The enhancement of different physical properties in polymer nanocomposites is highly dependent on the nature of nano filler and the nature of interfacial adhesion.

2.7 Nanomaterials as Promising Filler in Polymer Based Bionanocomposites

2.7.1 Nanoclay

There are many inorganic nano fillers which are widely used in different industrial and biomedical application, but the use of nanoclays with polymers is huge in literature to enhance the mechanical and gas barrier performance of the material. Nanoclays are layered silicate materials with thickness ~1 nm and the lateral dimension ranging from 30 nm to several microns. The basic building blocks of nanoclays are octahedral and tetrahedral sheets. In tetrahedral sheet, the silicon–oxygen tetrahedra are linked to neighboring tetrahedra by sharing three corners while the fourth corner of each tetrahedron forms a part to adjacent octahedral sheet (Fig. 2.5a). The octahedral sheet is usually composed of aluminum or magnesium in six fold coordination with oxygen from the tetrahedral sheet and with hydroxyl. Interlayer possesses net negative charge which is due to the ionic substitutions in the sheets of clay minerals. The layer charge is neutralized by cations which occupy the interlamellar. These interlamellae cations can be easily replaced by other cations or molecules as per required surface chemistry and hence called exchangeable cations. Na^+, K^+, Mg^{2+} and Ca^{2+} are among common exchangeable cations present in the interlayer which are exchanged with other required cations. The clay has immense use in architecture, in industry and in agriculture. It is used for the preparation of bricks and for the manufacturing of tile for wall and floor coverings. Due to high aspect ratio and layered structure of nanoclay, they are chosen as a good candidate for reinforcement in polymer nanocomposites (Zhang et al. 2017). Depending on the synthetic route of polymer/clay nanocomposites, they have shown different structural arrangement between clay platelets and polymeric chains. These structures are named intercalated and exfoliated structures (Fig. 2.5b). Exfoliation refers the high degree of dispersion of clay platelets within polymeric phase and shows better mechanical performances as compared to the conventional and intercalated structures.

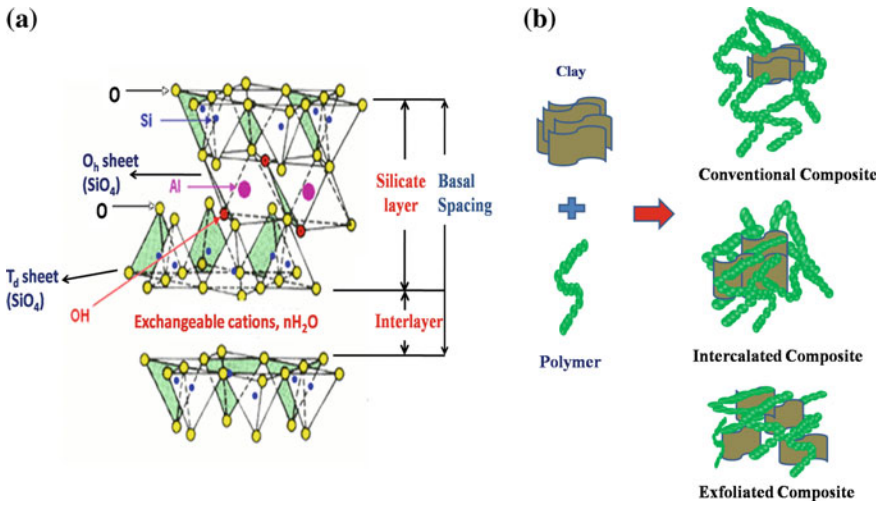

Fig. 2.5 **a** Structure of clay and **b** Structural arrangement of clay within polymer nanocomposites

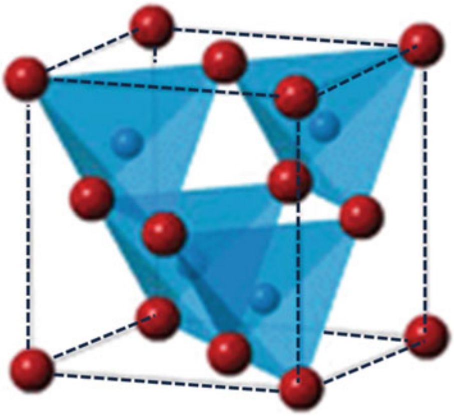

Fig. 2.6 Structure of silicon carbide

2.7.2 Nano Silicon Carbide

Nano silicon carbide is an important non-oxide ceramic material (Fig. 2.6) having diversified industrial applications due to its exclusive properties such as, high melting point, oxidation resistance, high erosion resistance, high hardness and strength, chemical and thermal stability, etc. (Benea et al. 2001). Silicon carbide can occur in more than 250 crystalline forms called polytypes and are widely used in making of polymer nanocomposites.

2.7.3 Nano Calcium Carbonate

Calcium carbonate is one of the most abundant biomaterials and one that can be grown easily under laboratory condition. The thermodynamically stable form of $CaCO_3$ under normal conditions is hexagonal β-$CaCO_3$ (calcite) (Fig. 2.7). Other forms can be prepared, the denser, (2.83 g/cc) orthorhombic λ-$CaCO_3$ (aragonite) and μ-$CaCO_3$, occurring as the mineral vaterite. It is one of the most commonly used inorganic filler for thermoplastics, such as poly (vinyl chloride) (Xie et al. 2004) and polypropylene (PP) (Lin et al. 2008). A lot of efforts have been devoted to surface-modified $CaCO_3$ particles to increase the polymer–filler interactions and reported enhancement of mechanical properties. The introduction of above-cited nanoparticles, i.e., nanoclay, nano SiC and nano $CaCO_3$ into starch matrix are found to improve the fire retardant, oxygen barrier, thermal and mechanical properties.

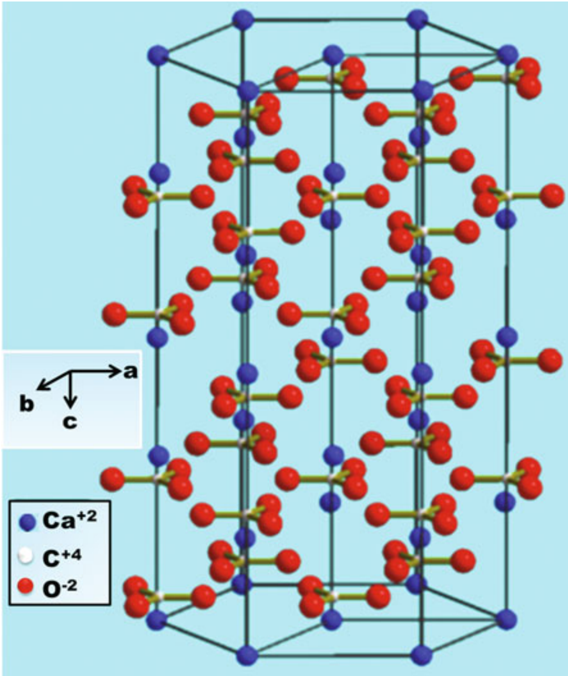

Fig. 2.7 Crystal structure of calcite (most stable polymorph of calcium carbonate)

2.8 Responsible Properties of Bionanocomposites for Packaging Applications

2.8.1 Fire Retardant Properties

Fire retardant properties of packaging materials are simply related to their ability of protecting the packed items from fire. Some materials like benzene, cyclohexane, acetone, alcohols are highly flammable. On the other hand, diesel, fuels, motor oils, kerosene are also combustible liquids. Therefore, these types of materials should be packed with the fire retardant materials. Limiting oxygen index (LOI) is a parameter that is used to compare the fire retardant properties of the materials. Higher the value of limiting oxygen index, higher will be the amount of oxygen requires burning the sample. In order to develop the fire retardant property in biopolymer starch, different wt% of nanoclay is incorporated within starch matrix through simple solution casting technique (Swain et al. 2014).The exfoliation of clay platelets within starch is achieved through the ultrasonication technique. The parametric estimation of LOI of nanoclay reinforced starch bionanocomposites of different composition and virgin starch is calculated and compared to understand the fire retardant nature of the materials. From Fig. 2.8, it is observed that with increasing the clay content in starch matrix, the value of LOI % increases. At 10 wt% of loading, the value of LOI is

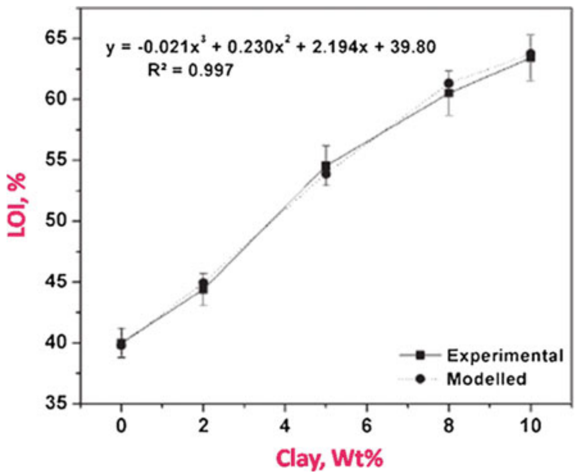

Fig. 2.8 Limiting oxygen index of starch/clay bionanocomposites as a function of wt% of clay (Swain et al. 2014)

increased 58.5% more as compared to the virgin starch. At high loading of clay and the effect of ultrasound leads to the effective dispersion of the layered clays within starch, so that a strong barrier is formed due to the tacoid orientation of the clay platelets. Uniformly, dispersed clay platelets also insulate the underlying polymer from heat source.

2.8.2 *Oxygen Barrier Properties*

As it is observed that due to the incorporation of clay platelets within starch, the fire retardant property is developed, it must be correlated with the oxygen barrier performance of the materials (Swain et al. 2014). The oxygen barrier property is measured in terms of the oxygen permeability value. Lower the value of oxygen permeability, higher will be the barrier performance. Figure 2.9 represents the oxygen permeability plots of starch bionanocomposites with different wt% of nanoclay loading. With increasing the clay content, the oxygen permeability is found to fall, and at 10 wt% of clay loading, the oxygen permeability is reduced to 69% more than virgin starch. Due to the porous structure and highly hydrophilic nature of starch, starch itself shows a very high value of oxygen permeability. But when organically modified nanoclays are inserted within starch, porous structure is eliminated and a torturous path is generated. Generally, the torturous path is created for the high degree of exfoliation of clay platelets in starch. The torturous path in highly exfoliated nanocomposite forces the gas to permeate through a longer path than conventional composites. To enhance the oxygen barrier performance, the increase in path length is a critical factor that depends upon the high aspect ratio of clay platelets and volume fraction of the filler in bionanocomposites. To ensure the

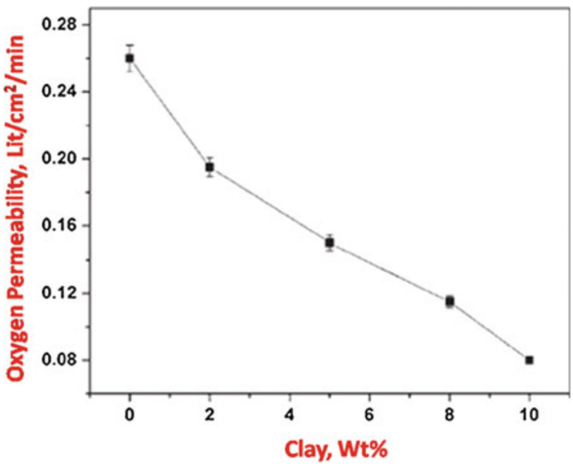

Fig. 2.9 Oxygen permeability of starch and Starch/clay bionanocomposites as a function of wt% of clay (Swain et al. 2014)

accuracy of the experimental data, a model regression is drawn and it is observed that experimental values are well fitted with third-order polynomial equation (R^2 = 0.997).

2.8.3 *Thermal Properties*

Thermal stability of the packaging material is another important issue that should be taken into account during the development of packages for the better safety of the products. If the packages are not enough thermally stable, then they may degrade and make contamination of the product. Thermally stable nano SiC reinforced starch bionanocomposites are synthesized through simple solution casting method in aqueous medium (Dash and Swain 2013). Nano SiC is introduced in the starch solution as aqueous suspension and allowed to disperse through simple stirring and sonication. Nano SiC is a non-oxide ceramic material and is highly thermally stable. Nano SiC remains in its initial form in the temperature range of 30–800 °C. Due to incorporation of nano SiC in starch, the thermal stability of starch/SiC bionanocomposites is enhanced (Fig. 2.10). With increasing the nano SiC, thermal stability of starch/SiC bionanocomposites increases and at 10 wt% of nano SiC, the char residue is increased to 40%. From the TGA profile, it has been observed that all starch/SiC bionanocomposites including virgin starch show three-step decomposition patterns. In first step, at about 100 °C all materials are gone through the loss of surface water. In second step, partial thermal decomposition of the bionanocomposite is occurred, whereas, in third step, complete decomposition and oxidation are occurred. The final degradation of starch is occurred at 330 °C, whereas, in bionanocomposites the final degradation is occurred at higher temperature as compared to virgin starch.

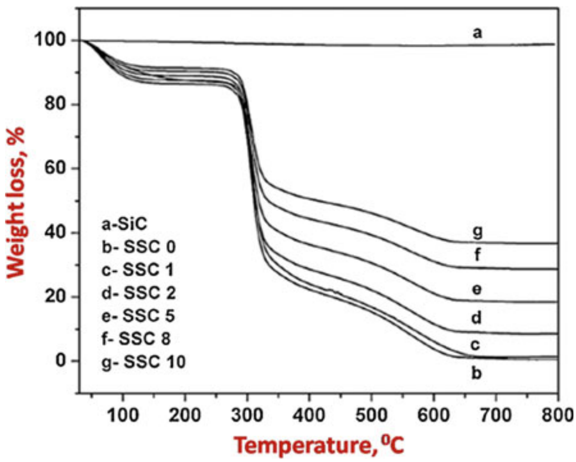

Fig. 2.10 Thermo gravimetric analysis curves of starch, SiC and Starch/SiC bionanocomposites at different weight % of Silicon Carbide (Dash and Swain 2013)

2.8.4 *Mechanical Properties*

Starch films are brittle in nature and, therefore, cannot be processed as film. But the incorporation of poly vinyl alcohol (PVA) in starch is a well-known way to obtain the films (Majdzadeh-Ardakani and Nazari 2010). As PVA is a highly hydrophilic in nature with numerous number of hydroxyl (–OH) groups, it has wide applicability as binder and adhesives. But the combination of starch and PVA is not enough to obtain the thin films with high-mechanical strength. Due to enhance the mechanical strength of starch/PVA thin film, nano calcium carbonate ($CaCO_3$) particles are incorporated through simple solution casting technique in aqueous medium (Kisku et al. 2014). The plot of tensile strength of starch/PVA/$CaCO_3$ nanocomposite thin films with various wt% nano $CaCO_3$ is shown in Fig. 2.11. The tensile strength of

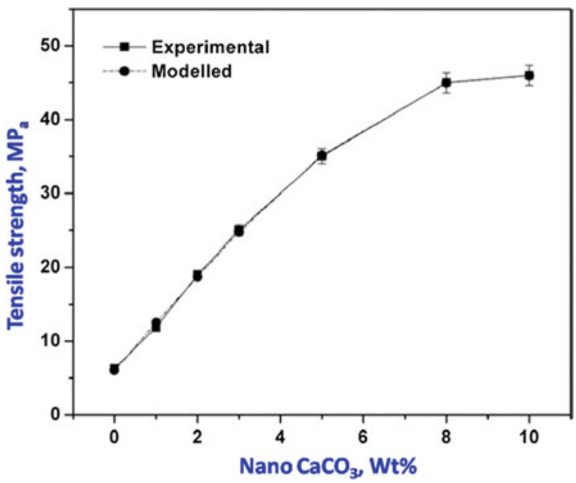

Fig. 2.11 Tensile properties of starch/Polyvinyl alcohol/Calcium Carbonate nanobiocomposite films and its modeled graph (Kisku et al. 2014)

starch/PVA thin film is 6 MPa. It is due to the strong intermolecular hydrogen bonding between starch and PVA. With incorporation of nano $CaCO_3$, the tensile strength of starch/PVA/$CaCO_3$ is increased and at 10 wt% of nano $CaCO_3$, the tensile strength is increased to above 40 MPa. It is due to the strong interfacial adhesion between uniformly distributed nano $CaCO_3$ and starch/PVA co-polymeric matrix. Similar explanations are also reported of the earlier study during the enhancement of tensile properties of polymers due to incorporation of nano $CaCO_3$.

2.9 Concluding Remarks

Packaging is a well-groomed technology dealing with the safety storage and handling of daily needs. Packaging technology is mainly divided into three sectors and these are process of designing, evaluation and production of packages. Depending on the type of product, packaging has been introduced in several ways. Different types of packaging are included bulk chemical packaging, medical device packaging, pharmaceutical packaging and retail food packaging. There are several reasons for doing packaging and these are safety, brand visibility, theft prevention, etc. Some packages contain oxygen absorbency to extend the self-life of packed items. Packages should have the features that can add convenience in distribution, handling, stacking, display, sale, opening, reclosing, use, dispensing, reuse, recycling and ease of disposal. With the ever-increasing market race, advertisement of the products through attractive and unique packages has opened a new age of packaging technology. Package labeling includes product specification, storing condition and the method of use. Labeling is highly used by the marketers to encourage potential buyers to purchase the product. In packaging technology, manipulation of consumer's behavior is one of the main issues that should be taken into account during the designing of product packages. The well-known "theory of conditioning" of Ivan Pavlov is widely used into the market place to control the consumer's choice. Although we cannot avoid the demand of plastics in food packaging, simultaneously we cannot deny the problem of environmental pollution. Therefore, researchers are running behind to fabricate the bionanocomposite-based packaging materials. Some essential features of packaging material like fire retardant, oxygen barrier, thermal and mechanical properties are introduced in highly biodegradable polysaccharide starch through simple solution casting techniques by the dispersion of nanoclay, nano SiC and nano $CaCO_3$.

References

Avella M, Errico ME (2000) Preparation of PHBV/starch blends by reactive blending and their characterization. J Appl Polym Sci 77:232–236

Benea L, Bonora PL, Borello A, Martelli S (2001) Wear corrosion properties of nano-structured SiC–nickel composite coatings obtained by electroplating. Wear 249:995–1003

Carroccio S, Rizzarelli P, Puglisi C, Montaudo G (2004) MALDI investigation of photooxidation in aliphatic polyesters: poly (butylene succinate). Macromolecules 37:6576–6586

Coles R, McDowell D, Kirwan MJ (eds) (2003) Food packaging technology. CRC Press. Taylor and Francis Group, London

Dash S, Swain SK (2013) Synthesis of thermal and chemical resistant oxygen barrier starch with reinforcement of nano silicon carbide. Carbohydr Polym 97:758–763

Godbole S, Gote S, Latkar M, Chakrabarti T (2003) Preparation and characterization of biodegradable poly-3-hydroxybutyrate–starch blend films. Biores Technol 86:33–37

Kai W, Hua L, Zhao L, Inoue Y (2006) Synthesis of novel star shaped poly (ε-caprolactone) utilizing fullerene as the molecular core. Macromol Rapid Commun 27:1702–1706

Kisku SK, Swain SK (2012) Study of oxygen permeability and flame retardancy properties of biodegradable polymethylmethacrylate/starch composites. Polym Compos 33:79–84

Kisku SK, Sarkar N, Dash S, Swain SK (2014) Preparation of starch/PVA/$CaCO_3$ nanobiocomposite films: study of fire retardant, thermal resistant, gas barrier and biodegradable properties. Polym Plast Technol Eng 53:1664–1670

Kong W, Wang W, Gao J, Liu T, Liu Y (2011) Oxidized starch films reinforced with natural halloysite. J Mater Res 26:2938–2944

Lin Y, Chen H, Chan CM, Wu J (2008) High impact toughness polypropylene/$CaCO_3$ nanocomposites and the toughening mechanism. Macromolecules 41:9204–9213

Majdzadeh-Ardakani K, Nazari B (2010) Improving the mechanical properties of thermoplastic starch/poly (vinyl alcohol)/clay nanocomposites. Compos Sci Technol 70:1557–1563

Oishi A, Zhang M, Nakayama K, Masuda T, Taguchi Y (2006) Synthesis of poly (butylenes succinate) and poly (ethylene succinate) including diglycollate moiety. Polym J 38:710–715

Pachauri M (2001) Consumer behaviour: a literature review. Mark Rev 2:319–355

Psomiadou E, Arvanitoyannis I, Biliaderis CG, Ogawa H, Kawasaki N (1997) Biodegradable films made from low density polyethylene (LDPE), wheat starch and soluble starch for food packaging applications. Part 2. Carbohydr Polym 33:227–242

Rosa DS, Guedes CGF, Pedroso AG, Calil MR (2004a) The influence of starch gelatinization on the rheological, thermal, and morphological properties of poly (ε-caprolactone) with corn starch blends. Mater Sci Eng C 24:663–670

Rosa DS, Lotto NT, Lopes DR, Guedes CGF (2004b) The use of roughness for evaluating the biodegradation of poly-β-(hydroxybutyrate) and poly-β-(hydroxybutyrate-co-β-valerate). Polym Test 23:3–8

Sabino MA, Feijoo JL, Muller AJ (2000) Crystallisation and morphology of poly (p-dioxanone). Macromol Chem Phys 201:2687–2698

Swain SK, Patra SK, Kisku SK (2014) Study of thermal, oxygen-barrier, fire-retardant and biodegradable properties of starch bionanocomposites. Polym Compos 35:1238–1243

Wee YJ, Kim JN, Ryu HW (2006) Biotechnological production of lactic acid and its recent applications. Food Technol Biotechnol 44:163–172

Willett JL, Shogren RL (2002) Processing and properties of extruded starch/polymer foams. Polymer 43:5935–5947

Xie XL, Liu QX, Li RKY, Zhou XP, Zhang QX, Yu ZZ, Mai YW (2004) Rheological and mechanical properties of PVC/$CaCO_3$ nanocomposites prepared by in situ polymerization. Polymer 45:6665–6673

Zhang JF, Sun X (2004) Mechanical properties of poly (lactic acid)/starch composites compatibilized by maleic anhydride. Biomacromolecules 5:1446–1451

Zhang G, Wu T, Lin W, Tan Y, Chen R, Huang Z, Qu J (2017) Preparation of polymer/clay nanocomposites via melt intercalation under continuous elongation flow. Compos Sci Technol 145:157–164

http://www.springer.com/978-3-319-67318-9

Bionanocomposites for Packaging Applications
Jawaid, M.; Swain, S.K. (Eds.)
2018, XVIII, 290 p. 102 illus., 68 illus. in color.,
Hardcover
ISBN: 978-3-319-67318-9