Potentials of Fibrous and Nonfibrous Materials in Biodegradable Packaging

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Abstract Packaging is a, essential requirement for fruits, vegetables, agricultural crops, food products, and other commodities to provide the requisite protection from physical damage, contamination, deterioration; to increase shelf life; and facilitate need-based supply from the producer to the consumer. The packaging material should be physically and mechanically strong and should not add any foul odor to the packed product. In the past, for packaging of the above-mentioned products as well as various industrial goods has been made of traditional to advanced materials such as metal and glass; ordinary, coated, and laminated paper; corrugated paper box; gunny sack; textile bag; bamboo slit; wooden box; biodegradable film; nonbiodegradable plastic/film; composite; and nanocopmosite/biocomposite, all of which have been widely used. During the past 50 years, synthetic polymers have been found to steadily replace traditional packaging materials because of their advantages of low cost, low density, inertness, resistance to microbial growth, thermoplasticity, and transparency. However, their usage currently is being partially restricted because they are not totally recyclable and/or biodegradable and thus lead to serious environmental problem. This has resulted in the development of biodegradable polymers/films such as starch, polylactic acid, protein-based film, poly-beta-hydroxyalkanoates (PHB), etc. It has been possible to enhance physico-mechanical and functional properties of such polymers by incorporating organic and inorganic nanoparticles such as silver, titanium, chitosan, cellulose, clay, starch, silica, and zein. Similarly, traditional

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to coated/laminated paper/paper board, jute fabric, and the corrugated fibre board have been utilized for conventional to high-end packaging.

Keywords Biodegradable packaging · Fibrous · Jute · Nanocopmosite · Paper box

1 Introduction

Packaging is essential for fruits, vegetables, crops, and other commodities, including industrial products, to provide protection from physical damage, contamination, and deterioration as well as to increase shelf life. Packaging also ensures optimum distribution and storage costs, consumer convenience, and preservation of product quality and taste and facilitates need-based supply of the packaged goods from producer to consumer. Often such packaging, traditional to smart materials—such as metal and glass, plain, coated, and laminated paper, corrugated paper box, fabric, gunny sack, bamboo slit, wooden box, biodegradable film, nonbiodegradable plastic/film, composite, and nanocopmosite/biocomposite materials—are widely used. Packaging materials should possess strong physical and mechanical resistance properties to the nonthermal process (Galic et al. 2011). Nonthermal processes do not utilize increased temperature to inactivate decomposition of microorganisms and enzymes. All of the packaging materials can be broadly categorized into primary, secondary, and tertiary packaging. India is the second largest producer of fruits and vegetables next to China.[1,2] The country is also gifted with an abundance of different types of fruits and vegetables. Still, consumers are bereft of good-quality fruits and vegetables due to damage and/or spoilage of approximately 20–30 % such products during transportation (see Footnotes 1 and 2).[3,4] Therefore, a good package must withstand the stress and strain of long-distance transportation, multiple handling, and change in climatic conditions at different storage places. Several technological advancements have taken place during the past 20 years in the packaging of food products with the evolution of the society and its lifestyles. Indications are strong and clear from recent research and developments that food packaging will continue to evolve in response to the increased consumer needs and futuristic demands. The proper selection and optimization of

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[1] http://theglobaljournals.com/paripex/file.php?val=June_2013_1371303434_72a9a_08.pdf, dated 30-06-2015.

[2] http://www.nird.org.in/NIRD_Docs/rs2013/RS%2091.pdf.

[3] http://www.itfnet.org/gfruit/Slides/Session%202/Marketing%20of%20Fruits%20in%20India%20-%20Present%20Practice%20and%20Future%20needs.pdf, dated 30-06-2015.

[4] http://www.business-standard.com/article/economy-policy/reducing-wastage-of-fruits-vegetables-is-the-key-focus-since-it-would-help-to-address-inflation-union-food-minister-box-attached-114091800774_1.html, dated 30-06-2015.

packaging materials are important to food manufacturers due to the associated aspects of economics, marketing, logistics, distribution, environmental impact, and consumer demands. Today, the packaging industry relies strongly on the use of petroleum-derived plastic materials, which is raising concerns on both environmental and economic impacts (Lavoine et al. 2014). In addition to traditional packaging materials, new research is focused on functional packaging materials, such as antibacterial and conductive, to improve product quality and keep it free from microbial spoilage.

The production of plastic materials for packaging application has seen a dramatic increase in the last two decades, and synthetic polymers have also been steadily replacing traditional packaging materials, such as paper, glass, metals, etc., during the past 50 years mainly because of their low cost, low density, inertness, ease of availability, resistance to corrosion, softness, transparency, and possessing the desirable physical (e.g., barrier and optical) and mechanical properties (Siracusa et al. 2008). Most of the plastics are made of chemicals that are derived from crude petroleum oil. However, their use is now being restricted because they are not totally recyclable and/or biodegradable and thus pose a serious threat to the environment. Similar to synthetic and nonbiodegradable polymer-based packaging materials, textile (fibrous)-based packing materials also play a crucial role in packaging applications. Different textile structures, especially designed for the packaging of food grains, sugar, rice, cement, other commodities, and industrial goods, are known as "Packtech" in technical textile parlance. The textile structures include use of both natural fibres, such as jute and cotton, and synthetic petroleum based fibres, such as polyester, polyethylene, polypropylene, etc. Uncoated and coated/laminated textiles, as well as paper-/pulp-based single to multilayer bags/structures, are also used as a shopping bags, food packets, and in the packaging of agricultural commodities due to their advantages of biodegradability, structural flexibility, and cost-effectiveness. A large quantity of jute hessian and sacking bags are also used as packaging materials in India because the country is the largest producer of jute fibre globally and the second largest exporter of jute goods, which ultimately supports the livelihood of 40 lakh farm families.[5]

The emerging nanotechnology has also been explored in the food and packaging sectors to enhance physical, mechanical, and functional properties of paper, film, and composite packaging materials (Youssef et al. 2013). Inorganic (e.g., silver and titanium) and organic nanoparticles (e.g., chitosan, cellulose, clay, starch, silica, and zein protein) with particle sizes in the range of 10–500 nm have been synthesized and incorporated into various biopolymers as fillers or coating materials to enhance the barrier, mechanical, and functional properties of packaging materials. The reinforcement of biopolymers using natural fillers, such as fibre, fibril, and organic nanoparticles, has attracted consideration because it is applied in an environment friendly manner for the development of the advanced materials. Such developed products are also environmentally consistent because both the

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[5] http://www.wbidc.com/images/pdf/annual_report/annual_report-09-10/Jute-Industry.pdf, dated 22-05-2015.

matrix and the filler are produced/derived from a renewable source, such as agricultural residues (e.g., parts of plants), or natural resources.

2 Importance of Packaging Material

Packaging is connected substantially and intimately to our everyday life, and its use has steady increased over time. With the development of the society and due to the availability of diversified food, e.g., fast food, junk food, and functional food, there has been an increasing requirement for traditional to high-end packaging materials, thus accelerating the development of new food-packaging materials. It is also expected that the packaging material should be physically and mechanically strong, should be free from contamination, and should not add any foul odor to the packed product. Therefore, a food product is packaged with the aim of storage, preservation, and protection for long-term use.[6] These are the three basic attributes demanded from food-packaging technology that must be perfected for better quality and handling of foods. A wide range of materials (e.g., metal, glass, wood, bamboo slit, paper- or pulp-based materials, fabric, and plastics) or combinations of materials (e.g., composites) are used for the packaging of foods and other commodities. The per-capita consumption of plastics in the United States, for example, is approximately 150 kg, in Europe approximately 20 kg, and in India approximately 5 kg (Nayak and Swain 2002). In developed countries, such as the United Kingdom, the proportion of food that is unfit for consumption before it reaches the consumer is 2 %, whereas in developing countries, where packaging is not as widespread, this loss can be in excess of 40 % (Davis and Song 2006). Almost all packed and traded consumer goods should fulfill at least one of the below-motioned functions in day-to-day life (Galic et al. 2011; Davis and Song 2006).[7]

- provide protection from physical damage, contamination, and deterioration
- offer sale appeal
- ensure product identity
- provide information about the product
- optimize distribution and storage costs
- provide consumer convenience and safety

Packaging materials play a major role in ensuring microbiological food safety by acting as a physical barrier preventing external contaminants coming into contact with the food. Additionally, they also fulfill the important function of protecting the packaged food from light, oxygen, and humidity, thus enhancing the shelf life of the product (Feichtinger et al. 2015). Packaging also plays a critical role in the

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[6] http://en.wikipedia.org/wiki/Packaging_and_labeling, dated 22-05-2015.

[7] http://en.wikipedia.org/wiki/Food_packaging, dated 22-05-2015.

postharvest handling and distribution of fresh and processed foods and other biomaterials (Pathare and Opara 2014). Similarly, in the long and complicated journey of fresh horticultural produce from producer to consumer, packaging is very important. Paper and cloth are flexible and lightweight, and generate less waste to discard in terms of packaging materials. Indeed, glass and metals have been used for packaging high-value products because they are corrosion resistant and stronger. On the other hand, the well-explored polymer (plastics) materials are extensively used for high-value packaging with an annual world production of approximately 200 MT and an average per-capita consumption of 100 kg (Mahalik and Nambiar 2010). This is due to their desirable properties such as tear resistance, tensile strength, excellent barrier to oxygen, thermal-seal ability, transparency, and softness; they are also inexpensive to produce (Mahalik and Nambiar 2010). All packaging materials can be broadly categorized into the following three groups: primary, secondary, and tertiary.

Primary packaging: Primary packaging usually remains in contact with the goods taken home by consumers. The most common types of materials used in this category are paper or pulp, glass, metals (aluminum and steels), and plastics. Paper- or pulp-based materials, such as wrapping paper, carton boxes, disposable cups and plates, bags, and envelopes, and corrugated cardboard, are used as both primary and, to some extent, secondary packaging.

Secondary packaging: Secondary packaging includes larger packaging, such as boxes, used to carry a number of primary packaged goods.

Tertiary packaging: Tertiary packaging refers to packaging, such as wooden pallets and plastic wrapping, used to assist in the transport of large quantities of goods.

Secondary and tertiary packaging materials are normally used in larger quantities and have less material variation; thus, recollecting and sorting them by wholesalers or retailers for recycling or reuse are much easier. Unlike secondary or tertiary packaging, primary packaging materials are not only more dispersed into households but also are mostly mixed, contaminated, and often damaged, and therefore they pose considerable challenges in recycling or reuse (Davis and Song 2006).

Currently a large number of petrochemical-based polymers, namely, PET, PP, PE, PS, and PA, are being used for the packaging of foods, crops, chemicals, fertilizers, and various industrial products owing to their low cost, light weight, inertness, transparency, and availability in large quantity. Because they are commonly derived from petroleum origin, they are nonbiodegradable and difficult to recycle or reuse due to their mixed levels of contamination and composition in addition to the presence of different polymer additives. A large number of traditional-to-smart fibrous and nonfibrous materials (e.g., metal, paper, coated and laminated paper, fabric, gunny sack, coated/laminated fabric, corrugated paper box, bamboo slit, wooden box, etc.) are widely used in the packaging (e.g., shopping bags, food packing, industrial products, fertilizer, cement, tea, etc.) of agricultural crops and commodities due to their biodegradability, their flexible to semi-flexible structure, and their cost-effectiveness. Also, in the recent years there has been a paradigm shift toward the development of biodegradable polymers and packaging materials, and some of the developments that are getting attention in this context are starch, polylactic acid, protein-based film, poly-beta-hydroxyalkanoates (PHB), etc. Their inherent physical, mechanical, and functional properties, and the incorporation of various micron- to nano-size fillers, will be discussed in detail in successive sections of this chapter.

3 Biodegradable Packaging Materials

The current global consumption of plastics is >200 million tonnes with an annual growth rate of approximately 5 %, which represents the largest field of application of crude oil (Siracusa et al. 2008). Until now, petrochemical-based plastics, such as polyethylene terephthalate (PET), polyvinylchloride (PVC), polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyamide (PA), have been increasingly used as packaging materials because of their techno-economic-mechanical advantages of availability in a large quantity at a relatively lower cost, good tensile and tear strength, good barrier to oxygen, carbon dioxide, anhydride, and aroma compounds, heat sealability, thermoplasticity easiness in making flexible and semi-flexible bag/structure, and relatively inertness to the packaged product (Vigneshwaran et al. 2011). Plastics or synthetic polymers are the long-chain molecules that started to substitute for natural materials in almost each and every area of applications approximately half a century ago; currently plastics have become an indispensable part of our lives (Shah et al. 2008). With the passage of time, the stability and durability of plastics have been improved continuously; hence such materials are now considered synonymous for materials that are resistant to many environmental influences. The basic materials used for making plastics are extracted from oil, coal, and natural gas. However, they are neither totally biodegradable nor recyclable, thus causing adverse effects to the environment, especially soil and water (Mahalik and Nambiar 2010; Shah et al. 2008). Plastic packaging materials are also often contaminated by foodstuff and biological substances; therefore, their recycling is impracticable and, most of the time, economically inconvenient (Siracusa et al. 2008). As a result, a several thousand tons of such materials are land-filled, which increases the environmental problem day by day. Due to the adverse effect of such fossil fuel-based polymer (99 % of plastics are made from fossil fuel) in packaging, there has been a paradigm shift in recent years toward the development of biodegradable polymers and packaging materials to address such environmental issues (Mahalik and Nambiar 2010; Azeredo 2009). Biodegradation is the process by which carbon-containing chemical substrates are decomposed in the presence of enzymes secreted by living organisms.

More recently the development of biodegradable packaging materials from renewable natural resources has received widespread government support in European Union countries. The field of application of biodegradable polymers in food-contact articles includes disposable cutlery, drinking cups, salad cups, plates,

Fig. 1 Different packaging materials made of jute and cotton

overwrap and lamination film, straws, stirrers, lids, cups and plates, and containers for food dispensed at delicatessens and fast-food establishments. By biological degradation, such biodegradable polymers produce water, carbon dioxide, and inorganic compounds but no toxic residues. According to the European Bioplastics Norm, biopolymers made of renewable resources must be biodegradable and especially compostable so they can act as fertilizers and soil conditioners at the end of their life (Siracusa et al. 2008). Bioplastics, such as plastics, also present a large spectrum of applications such as collection bags for compost, agricultural foils, horticultures, nursery products, toys, fibres, textiles, etc.[8] Some of the explored biodegradable polymers suitable for packaging application are starch, poly(lactic acid) (PLA), cellulose, zein protein, poly-beta-hydroxyalkanoates (PHB), polyhydroxy-*co*-3-butyrate-*co*-3-valerate (PHBV), and others. One of the most promising biopolymer is PLA obtained from the controlled polymerization of lactic acid monomer, which is obtained from the fermentation of sugar feedstock, corn, etc., which are in turn obtained from renewable resources; thus, they are readily biodegradable. PLA is a versatile recyclable and compostable polymer with high transparency, high molecular weight, and good processability and water-insolubility. Currently it is used in food-packaging applications only in the cases of products with short shelf lives. Such properties have also been observed in starch for packaging applications. Similar to recent development in biodegradable polymers and films, natural fibres-based woven and nonwoven fibrous structures have also been used in biodegradable packaging for a long time. For example, cellulosic cotton and lingo-cellulosic jute fibres have extensively been used for the packaging of agricultural crops, sugar, fertilizer, and shopping bags as shown in Fig. 1.

4 Natural Fibres-Based Packaging Material

One of the important uses of textiles is the manufacturing of various bags and sacks not only from traditional cotton, flax, and jute fibres but also from the synthetics such as polypropylene.[9] Different textile materials that are especially used

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[8] www.european-bioplastics.org, dated 22-05-2015.

[9] http://www.technotexindia.in/packaging-textiles.html, dated 22-05-2015.

for the packaging of various commodities fall under the group of “Packtech” under the umbrella defining the technical textiles or functional textiles. Products covered under Packtech range from polymer-based bags used for industrial packing to jute-based sacks used for packaging of food grains and tea. These kinds of packaging materials (excluding jute) are also called “flexible packaging materials.” The ability to reuse these containers in many applications in place of disposable bags and sacks further supports their wider use. Some other products under Packtech include polyolefin-woven sacks, leno bags, wrapping fabric, jute hessian and sacks (including food-grade jute bags), soft-luggage products, tea bags (filter paper), and others.[10]

4.1 Jute Textile-Based Packaging Material

In India as per the government norms as published in The Gazette of India under section 376, a minimum 90 % of food grains (after providing for upfront exemption of 3.5 lakh bales) and 20 % of sugar of the total production of the country are to be packed in jute fibre-based hessian and sacking bags (The Gazette of India, Extraordinary, Part II-Section 3-Sub-section (II), Ministry of Textile-Order dated 13th Feb 2015). Natural fibre, such as jute, is most suitable for the packaging of sugar and other agricultural food grains owing to its advantage of low cost, biodegradability, eco-friendliness, produced from renewable sources, yet it is capable of satisfying the standards for safe packaging compared with synthetic HDPE and PP bags. Jute packaging material means jute fibre, jute yarn, jute twine, jute sacking cloth, hessian cloth, jute bags, or any other packaging material that contains jute fibre not less than 75 % by weight. The role of the jute industry in the Indian economy is very important because it is the major industry in the eastern part of India, particularly in the state of West Bengal (see Footnote 5). Jute, an important cash crop, is intercropped before paddy transplantation in most parts of the country. India is the largest producer of jute globally and the second largest exporter of jute goods, which ultimately supports 40 lakh farm families’ livelihood. Jute fibre is mostly used for the packaging of agricultural crops, rice, sugar, tea, potato, etc. However, with the development of petroleum-based low cost and lightweight synthetic bags, such as high-density polyethylene (HDPE) and polypropylene (PP), jute bags have slowly been replaced by such bags. As a result, the jute industry has been phased out from Europe, America, and the far East, and today it survives only in the Indian subcontinent and, to some extent, in Brazil and China. Raw jute in the form of bales is processed in the jute industry to produce hessian, sacking, jute yarn, bags, and other useful products. Raw jute bales weighing approximately 150 or 180 kg with or without a top portion being cut generally come to the factory and are assorted according to their suitable end-use, such as hessian weft,

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[10] http://textilelearner.blogspot.in/2013/01/packtech-textile-packaging-material.html, dated 22-05-2015.

sacking wrap, sacking weft, etc. Before spinning, the fibres are softened in softener or a spreader machine to lubricate and/or to soften the bark and the gummy portion of the raw jute fibre by application of an oil–water emulsion.

A large amount of jute-based hessian and sacking bags is procured by the Government of India for the packaging of agricultural food grains. Therefore, several standards have been specified for different end applications by the government. A numbers of bags or lap of fabrics, also called "cuts," whichever is applicable, are packed with the help of a packsheet and bailing hoops to form a compact package called a "bale." The standards have been formulated to mitigate the requirements of good packaging, which includes the degree of thrust-withstanding capacity, seam strength of the bags, and the prevention of leakage of packed material through the bag. A "lot" consisting of numbers of bales must fulfill all the requirements and criteria for conformity as specified in the standards. The requirement consists of standards and tolerance of length, width, ends/dm and picks/dm, weight, and moisture regain of the bag. Apart from this, acceptance criteria for strength and manufacturing defects of the fabric are also specified in the respective standard. For example, the Indian Standard (2nd Revision) for Textiles–Jute bags for packing of 50 kg of food grains was adopted by the Bureau of Indian Standards, and the draft finalized by the Jute and Jute Products Sectional Committee has also been approved by the Textile Division Council. The bags shall be made from a single piece of double warp, 2/1-twill weave jute sacking of uniform construction having a nominal mass of 579 g/m^2 with the warp running along the length of the bag (Indian Standard (IS) 2003). There shall be a single blue stripe or stripes woven along the length of the bag or the bag shall be without stripe as agreed between the buyer and the seller. The constructional parameters of such sacking bags are indicated in Table 1. This kind of bags is mostly suitable for the packing of wheat, rice, and similar coarse grains. However, for packing of other materials, the buyer and the seller may agree to the dimensions other than those specified in this standard. The sides of the bags shall be sewn with overhead or herakle stitches on the selvedge through two layers of the sacking, and the number of stitches per decimeter shall be 10 ± 1. In the defect test, a bag shall be termed as defective if it contains two or more major defects, such as the GAW (>1.5 cm), multiple broken/missing warp end (single, >25 cm long), multiple broken weft pick (two or more continuous regardless of length), float (>2 cm^2), gap stitching (stitches missing >1.5 cm), and corner gap (>1.5 cm).

Similar to the above-mentioned criteria, IS 15138: 2010 on jute bags for packing 50 kg of sugar is one of the most widely implemented standards because it covers comprehensive specifications of the raw material and their classification, dimensional requirements, physical and chemical characteristics, mechanical properties, sampling criteria, test requirements, and acceptance criteria as indicated in Table 2 (Indian Standard (IS) 2010). A jute sack is woven on conventional shuttle looms as well as modern rapier looms and it is usually available in plain and twill woven form. Jute sack, commonly known as "heavy goods," is loosely woven, weighs from 12 to 20 oz per yard, and comes in different widths depending on the kind of goods to be packed. They are commonly utilized for packaging

Table 1 Specification of jute bags for 50 kg of food grains packaging (Indian Standard (IS) 2003)

Sl. no.	Characteristics	Requirement		Tolerance
		Type A	Type B	
1	Bag dimension			
	(i) Outside length, cm	94	94	+4 cm, −0
	(ii) Outside width, cm	57	57	+4 cm, −0
2	Ends/dm	76	46	+4, −3
3	Picks/dm	28	50 (2 × 25)	+2, −2
4	Corrected mass/bag, g	665	665	+8 %, −6 %
5	Average breaking strength of fabric (Ravelled-strip method: 10 cm × 20 cm), Min., N (kgf)			
	(i) Warp way	1570 (160)	1570 (160)	–
	(ii) Weft way	1420 (145)	1420 (145)	–
6	Average seam strength (5 cm × 20 cm ravelled strip), Min. N (kgf)	490 (50)	490 (50)	–
7	Moisture regain, percentage, Max.	22	22	–
8	Oil content on dry de-oiled material basis, percentage, Max.	3	3	–

Type A Single warp, double weft woven on modern shuttleless loom
Type B Double warp, single weft woven on conventional shuttle loom

Table 2 Specifications of jute bag for 50 kg of sugar packaging (Indian Standard (IS) 2010)

Sl. no.	Characteristics	Requirement		
		Type A [Tolerance[a]]	Type B [Tolerance[a]]	Type C [Tolerance[a]]
1	Bag dimension			
	(i) Outside length, cm	87.5 [+3]	91.5 [+3]	91.5 [+3]
	(ii) Outside width, cm	58.5 [+3]	56.0 [+3]	56.0 [+3]
2	Ends/dm	68 [+4, −2]	47 [±2]	47 [±2]
3	Picks/dm	31 [+2, −1]	55 [+2, −1]	47 [+2, −1]
4	Corrected mass/bag, g [Tolerance in %, Max.]	630 [+7.5, −6]	475 [+7.5, −2]	405 + 32 Liner [+7.5, −2]
5	Average breaking strength of sacking (Ravelled-strip method: 10 cm × 20 cm), Min., N (kgf)			
	(i) Warp way	1570 (160)	1470 (150)	1470 (150)
	(ii) Weft way	1420 (145)	1765 (180)	1420 (145)
6	Average seam strength (5 cm × 20 cm ravelled strip), Min. N (kgf)			
	(i) Warp way	–	490 (50)	490 (50)
	(ii) Weft way	440 (45)	685 (70)	490 (50)
7	Moisture regain, percentage, Max.	22	17	17

[a] Value in the parenthesis is the tolerance limit/percentage

of bulky articles weighing 50–100 kg such as sugar, wheat, tea, rice, etc. Type A bags shall be made from a single piece of 568 g/m^2 plain-weave construction double-warp jute fabric with the warp running along the length of the bag. Type B and C bags shall be made from hessian having a mass of 417 and 354 g/m^2, respectively. The cloth shall be without stripes or shall have stripes woven along the length of the bag as per the agreement between the buyer and the seller. This kind of packaging bag for sugar shall be specifically manufactured from raw jute of Indian origin. The sides of the type A bag shall have herakle safety stitches per the standard norm, and type B and C bags shall be sewn with herakle stitches on the selvedge through the two layers of jute, and the bottom row edge shall be folded inside to a depth of at least 3.8 cm and then stitched at the mouth.

A similar specification for the laminated jute bags for the packaging of milk powder has also been standardized per the Indian Standard IS 12626: 1989 (Indian Standard (IS) 1989). Here, there are two types of bags: The Type 1 bag is made out of hessian fabric laminated with kraft paper on the outside and plastic film/kraft paper on the inside, uses bitumen as the bonding agent, and has a liner of kraft paper or plastic film stitched along the bag on the side and at the bottom. Type 2 bags (with GSM 270 g/m^2) are made of hessian fabric laminated with kraft paper on the outside, use bitumen as a bonding agent, and have two liners of kraft paper or plastic film stitched along the bag on the side and the bottom. The bags are required to be manufactured from the laminated hessian fabric with stitching on the side and the bottom to keep the kraft paper on the outer side of the bag. In this regard, low-density polyethylene (LDPE), high-density polyethylene (HDPE), high-molecular high-density polyethylene (HMHDPE), or polypropylene (PP) film shall be used. In case of low-density polyethylene film, the areal density of 23 g/m^2 or a thickness of 25 μm, and for other type of plastic films a minimum mass of 11.5 g/m^2 or a thickness of 12.5 μm, are recommended. The liner for food-grade material, i.e., the LDPE, HDPE, HMHDPE, or PP loose liner, shall be of minimum mass of 69 g/m^2 or thickness of 75 μm. The detail specifications, including the physical and mechanical properties, are also reported in this standard (Indian Standard (IS) 1989). The jute fabric has also been recommended for packing of fertilizer per the Indian Standard IS: 7406 (Part 1)-1984 (Indian Standard, IS: 7406 (Part 1) 1984). Double-warp jute tarpaulin bags are used conventionally for the packaging of fertilizer. Such bags frequently undergo adverse climatic conditions and transport hazards from factory to the farmer's field. The size of the bags is specified in such a way so they hold 50 kg of fertilizer. Bags suitable for lower bulk-density fertilizer are approximately 99 cm × 61 cm with a tolerance of ±3 cm. The specifications of the laminated jute bags manufactured from 380 g/m^2 fabric and 68 cm × 39 cm tarpaulin fabric have been covered in Part 2 of the same standard (Indian Standard 1986). Similar to other specifications, IS 9685: 2002 describes the textiles suitable for the packaging of sand (e.g., sand bags) (Indian Standard, IS 9685 2002). The bags shall be made from one continuous piece of 229 g/m^2 hessian, and each piece may be folded widthwise or lengthwise, but the bag length shall be in the direction of the warp of the fabric. If there is a requirement of rot-proofs by the buyer, the sand bags shall be finished with copper naphthenate per standard IS 11662. The outer length and width of the bag should be approximately 84 cm × 36 cm with a tolerance of +3 cm, and the mass of the bags shall be 160 and 180 g for nonproofed and rot-proofed bags, respectively. As per the Indian Standard IS 12269: 2013, cement shall be packed in any of the following bags: (1) jute sacking conforming to IS 2580, (2) light-weight jute fabric conforming to IS 12154, (3) jute synthetic union bags conforming to IS 12174, (4) multiwall paper sacks conforming to IS 11761, and (5) HDPE/PP woven sacks conforming to IS 11652 (2013). Thee bags shall be prepared in such a way that the cement capacity per bag will be approximately 50 kg. However, the net quantity of cement per bag may also be 25, 10, 5, 2, or 1 kg subject to the acceptable tolerances and packed in such bags per the mutual agreement between the purchaser and the manufacturer.

As per IS 1943, an A-twill bag shall be made from a single piece of double-warp, 2/l twill-weave jute sacking of uniform construction and having a nominal mass of 750 g/m^2 with the warp running along the length of the bag as indicated in Table 3. There shall be three blue stripes or simple stripes along the length of the bag as per agreement between the buyer and the seller (IS 1943 1995). The sides of the bags shall be sewn with overhead or herakle stitches on the selvedge through two layers of sacking with 9 to 11 stitches/10 cm. A line of safety union stitch with the above stitch density shall also be provided at the inner edges of the overhead or herakle stitches. The bags should preferably be free from weaving and sewing defects, such as missing picks, holes, cuts, tears, float, crushed selvedges, spots, stains, gap stitches, loose ends, and frayed ends, which might affect the end performance of the bag as a packaging material. The bag shall be made of 750 g/m^2 areal density fabric with 102 ends and 35 picks/dm where the acceptable tolerance limits are ±6 and ±2, respectively. The outer dimension of the bag shall be 112 cm in length and 67.5 cm in width, with a total bag-weight

Table 3 Specification of an A-twill jute bag for sugar packaging (Indian Standard 1995)

Sl. no.	Characteristics	Type A [Tolerance[a]]
1	Bag dimension	
	(1) Outside length, cm	112 [+4, −0]
	(2) Outside width, cm	67.5 [+4, −0]
2	Ends/dm	102 [+6, −6]
3	Picks/dm	35 [+2, −2]
4	Corrected mass/bag, g [Tolerance in %, Max.]	1200 [+10, −7.5]
5	Average breaking strength of sacking (ravelled-strip method: 10 cm × 20 cm), Min., N (kgf)	
	(i) Warp way	2000 (204)
	(ii) Weft way	1765 (180)
6	Average seam strength (5 cm × 20 cm ravelled strip), Min. N (kgf)	657 (67)
7	Moisture regain, percentage, Max.	22

[a] Value in the parenthesis is the tolerance limit/percentage

of 1190 g. It is recommended that the product should also ensure a warp and weft way breaking load of 2000 and 1765 N, respectively, and a seam-breaking load of 657 N.

Similar to an A-twill jute bag, the standard for a B-twill jute bag describes the construction details along with other requirements of the bag for the packing of 100, 93, and 75 kg of food grains (Indian Standard 1993). The corresponding bag size will be 122 × 67.5 cm, 112 × 67.5 cm and 106.5 × 61 cm, respectively, and all the bags should have 76 and 31 ends and picks/dm, respectively. The weight of the bag for the overhead stitch shall be 1110, 1020, and 880 g, respectively. It may be noted here that the packing of 50 kg of food grains is covered under IS 12650: 1989. The bag shall be made from cloth conforming to IS 3667: 1993. It should be made from a single piece of cloth preferably with the warp running along the length of the bag. For marking purposes, a blue stripe of single or double warp shall be placed per the agreement between the buyer and the seller. Similarly, the bags should also be free from the defects as stated previously.

The announcement to exempt 60 % of the output of the sugar industry from jute packaging has provided a breather to the industry. Earlier, under the Jute Packaging Materials Act (1987), sugar manufacturers had to package the entire product in jute bags.[11] A jute bag costs approximately Rs 35 for a 50-kg bag, which translates into a packaging cost of Rs 0.70/kg of sugar. On the other hand, a similar capacity, high-density polyethylene (HDPE) bags costs much less, approximately Rs 15, and hence the packaging cost becomes Rs 0.30/kg of sugar. Therefore, a shift from a jute bag to HDPE bags would result in savings of Rs 0.40/kg for sugar packaging. Assuming that the total production is 25 million tonnes and that the entire product is packaged in HDPE bags, the total savings for the industry would stand at Rs 1000 crore. However, because presently the government has allowed HDPE bags for only ≤80 % of the produce, the industry's savings would stand approximately at Rs 800 crore.

4.2 Other Textile-Based Packaging

Textiles meant for packaging include all the textile-based materials for packing of industrial, agricultural, and other goods. The demand for packing material is directly proportional to economic growth, industrial production, and trade to distribute goods both locally and internationally.[12] As discussed previously, packaging has provided new opportunities in the emerging marketplace regarding the growing environmental need for reusable/recycled/biodegradable packages and containers and natural fibres-based products. Sacks and bags made of traditional jute, cotton, or natural fibers are gradually making their way into the market by

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[11] http://www.business-standard.com/article/markets/packaging-shift-to-help-sugar-sector-save-rs-600-cr-a-year-112110800052_1.html, dated on 07-0502915.

[12] http://www.bch.in/packaging-textiles.html, dated 22-05-2015.

replacing those made from synthetic fibers. Those technical textiles, specially used in packaging and subsequent transportation applications, are called Packtech. Packtech includes not only heavy-weight, densely woven fabrics (bags and sacks for storage, flexible intermediate bulk carriers, and wrappings for textile bales and carpets) but also lightweight woven and nonwoven fabrics used for durable papers, tea bags, shopping bags, industrial product wrappings, woven strapping, light-weight mailbags, soft luggage, and coffee filters (see Footnote 12).[13]

5 Paper, Pulp, and Corrugated Boxes in Packaging

5.1 Paper/Paperboard and Paper Pulp in Packaging

The use of paper pulp in packaging has become more attractive compared with traditional materials, such as expanded polystyrene (EPS) foam, due to the advantages of low price of the recycled paper, low cost of production, and biodegradability (Gurav et al. 2003). It has been noticed that electronic equipment, such as computer monitors, could be better packed in a paper pulp packaging than the traditional expanded polystyrene packaging. Paper pulp is basically a composite materials made out of recyclable waste papers, such as newsprint or cardboard, that are made from naturally available materials consisting of wood fibres in a matrix of lignin and hemi-cellulose. In addition to the waste paper, the process requires only water and energy to produce the paper pulp. Hence, it helps in saving resources and becomes an “eco-comp” material. Paper/paperboard has great advantages compared with traditional plastic as packaging material in terms of cost and sustainability (Chen et al. 2013). The primary consumption of this kind of material is for producing various types of flexible, semi-rigid, or rigid packaging. Due to its overall advantages of cost-effectiveness, high flexibility, environmental friendliness, produced from renewable sources, and ease of recyclability, these types of packaging are used in the largest quantity as packaging materials throughout the world. The global paper-packaging market in 2011 was reported to be worth of 236 billion dollars USD (Chen et al. 2013). The typical composition of pulp is listed in Table 4. It has been reported that various jute-based raw materials, such as fibres, stick, mesta stick, whole plant, feshwa, root cuttings, caddis, etc., are a good source of cellulose and hence has been explored to produce paper-grade pulp and ultimately utilized to produce different grades of important papers and board. Similarly, an adhesive-bonded fabric of 110 g/m^2 has been developed to make light-weight carry bag.[14] Some of the bags produced from jute pulp/paper and light-weight jute fabric at ICAR—National Institute of Research on Jute and Allied Fibre Technology are shown in Fig. 2.

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[13] http://en.wikipedia.org/wiki/Technical_textile, dated 22-05-2015.

[14] www.nirjaft.res.in, dated on 29-06-2015.

Table 4 Composition of pulp (Gurav et al. 2003)

Material	Structure	Approximate weight (%)
Fibre		
Cellulose	Crystalline	45
Matrix		
Lignin	Amorphous	20
Hemi-cellulose	Semicrystalline	20
Water	Dissolved in matrix	10
Extractives	Dissolved in matrix	5

Fig. 2 Different utility bags produced from jute pulp/paper and lightweight jute fabric (see Footnote 14)

5.2 *Coated and Laminated Paper/Paperboard for Packaging*

Paper is widely used in food packaging because of its advantages of biodegradability and safety for the packaging of food items (El-Wakil et al. 2015). Nevertheless, the porosity and hydrophilic characteristics of paper can easily cause adsorption of water from the surrounding environment or food, thus resulting in loss of the paper's physical and mechanical properties in addition to fostering microbial growth. Hence, the coating/lamination of paper with other materials, such as plastic and metal (aluminium), to address the problems of porosity and hygroscopicity has been quite successful. However, this also decreases the biodegradability and recyclability of the paper. This has ultimately led to the use of biopolymers produced from natural resources as a promising alternative for packaging because they are abundant, renewable, biodegradable, inexpensive, and environmentally friendly. Polysaccharides biopolymers, such as starch, alginates, and chitosan, have been considered for paper-coating (El-Wakil et al. 2015). Lipid compounds, such as long-chain fatty acids and waxes and long-chain alkanes, can also be used as a coating material for paper and paperboard because of their inherent hydrophobic characteristic. Similarly, due to their wide availability, complete biodegradability, good film-forming ability, nontoxicity, good barrier property, and moderate cost, plant proteins have been popularly used for food packaging. It may be mentioned here that compared with whey protein and corn zein, soy protein and wheat gluten have the cost-advantage of being used as affordable packaging materials; however, the mechanical and barrier properties of wheat gluten must be further improved.

Guazzotti et al. (2015) reported the barrier properties of starch-coated paperboard against the migration of n-alkanes and mineral oils. Different types of starches and the presence of sorbitol as plasticizer were tested. For a biopolymeric coating, a 100 % virgin kraft-grade paperboard, unprinted and suitable for dry food, was used. Starch coatings were obtained from maize cationic waxy starch (30 %), maize cationic starch (10 %), or cationic starch mixture with high amylose content based on cereal and tuber starch (10 %). The thickness of the starch coating was in the range of 4.7–14.2 μm. The effective results obtained at 40 °C after 10 days demonstrated the results of the laboratory-scale coatings on paper against n-alkane (range C18–C26) migration compared with uncoated paperboard. Similarly, the use of paper/paperboard as packaging material is still limited because of its inferior water-resistant performance (Chen et al. 2013). Papers and paperboards are the sheet materials comprising an interlaced network of cellulose fibers that is intensely susceptible to water or moisture because it is hydrophilic in nature. To improve functional properties, in many cases an additional barrier coating or lamination of aluminum or plastic (PP or PLA) is incorporated in the paperboard to be used as corrugated box liners (Song et al. 2003; Rhim et al. 2007). However, such laminated packaging material is not only quite expensive, it also has poor recyclability compared with those produced only from paper. This has led to the development of an overprint varnish, another widely used cost-effective and simple protection technology. However, varnish is not a good water repellent. Chen et al. (2013) reported the preparation of a functional overprint varnish to significantly improve the water repellency of paperboard by its unique nanostructured morphology for printed packaging. This is an example of technology derived from biomimicking the water-repellent property of the lotus surface. The functional varnish helps paperboard to utilize its unique lotus-like properties, such as water and moisture-repellency, as well as anti-frost formation, thus resulting in better packaging appearance. The varnish was prepared by mixing silica nanoparticles with an average particle size of 7 nm, decamethylcyclopentasiloxane, polydimethylsiloxane, and nonionic surfactant p-octyl polyethylene glycol phenyl ether at a blend ratio of 3:57:9:1. The water-contact angle reflects an increasing trend of hydrophobicity with the increase of the modifying agent. It was found to reach ≥150° in paper packaging when the component of the modifying agent in the varnish was >30 wt%, clearly indicating a super-hydrophobic characteristic (Chen et al. 2013). When the smooth paper of the packaging was coated with unmodified and modified varnish of 20 %, it showed water contact angles of 99° and 110°, respectively. Figure 3 shows the photographs of 10 μL of water droplets on the surface of a packaging paper coated with (a) original varnish and (b) modified varnish comprised of 40 wt% of the modifying agent. Similar to varnish coating, protein can also be used as functional coatings for paper because it acts as a mechanical support for the packaging.

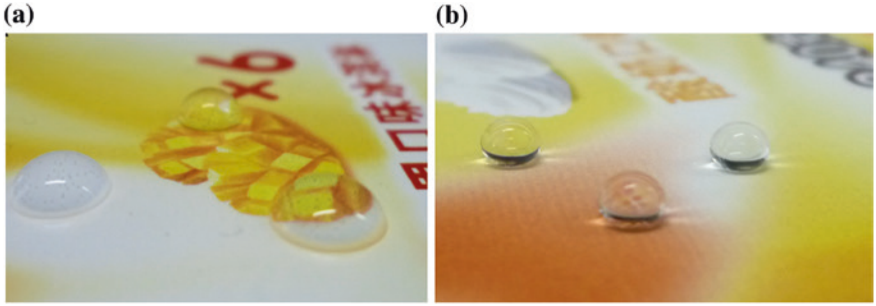

Fig. 3 Photographs of water droplet on the **a** original and **b** modified varnish-coated paper (Chen et al. 2013)

In the past, it has been observed that after application of several animal and vegetable proteins—such as caseinates, whey protein isolates (WPI) and concentrates (WPC), corn zein, wheat gluten (WG), and soy protein isolate (SPI) as coating materials of paper and paperboard, they have improved the surface and/or mass-transfer properties of the cellulosic substrate, such as resistance to oil, water, and grease and barrier properties against water vapour, without significantly changing their optical and mechanical properties (Guillaume et al. 2010). Guillaume et al. reported structural and surface features (e.g., water vapour) and gas barrier properties of wheat gluten (WG)-coated paper that could be influenced by certain features of the paper (2010). The transfer properties to water vapour, O_2, and CO_2 of WG-coated papers were significantly improved. Whereas the WG-coating was highly penetrative, the WG-treated paper (WG-TP) behaved as a microperforated material, and the WG-untreated paper (WG-UTP) as a WG film. Water and oil droplets were selected to reflect moisture and grease resistance, which are important criteria for their potential usage as a food packaging material. The water-wettability of WG-coated papers was found to decrease compared with their respective uncoated papers; however, this occurred to a greater extent for WG-TP (approximately 30-fold less) than that for WG-UTP (only 6-fold less).

EI-Wakil et al. (2015) reported the development of a bio-nanocopmosite by casting/evaporation of wheat gluten (WG), cellulose nanocrystals (CNC), and TiO_2 nanoparticles for food-packaging application. A significant improvement in the various properties was observed when 7.5 % CNC and 0.6 % TiO_2 were added to WG. The same composition was chosen to coat a commercial unbleached kraft paper sheet by way of one, two, and three layers of coating. A significant enhancement of 56 and 53 % in breaking length and burst index, respectively, was achieved for paper coated with three layers. This sample exhibited excellent antimicrobial activities, e.g., 100, 100, and 98.5 % against *S. cervisiae*, *E. coli*, and *S. aureus*, respectively, after 2 h of exposure to UVA light illumination. In the increasing domain of the application of sustainable packaging materials, paper and polymer nanocopmosites represent a novel class of packaging materials. Youssef et al. (2013) developed an alternative sustainable and promising material for antibacterial packaging applications. Paper sheets were made from rice straw coated with 5 or 10 % polystyrene (PS) nanocomposites using titanium dioxide nanoparticles (TiO_2-NPs), doped or undoped with silver nanoparticles (Ag-NPs). Polystyrene (PS), a thermoplastic resin with good processing properties, has been used in many applications including food packaging, domestic appliances, electronic goods, toys, household goods, and furniture. Silver (Ag) nanoparticles showed a better antibacterial efficacy than TiO_2 nanoparticles for all of the tested bacteria except for Staphylococcus. Paper coated with PS nanocomposites in the presence of TiO_2 and/or Ag nanoparticles improved tensile strength, water absorption, and air permeability of the coated sheets, especially when they were treated with 5 % TiO_2 without Ag nanoparticles (Youssef et al. 2013). Lavoine et al. (2014) reported a new paper-based packaging with antibacterial efficacy utilizing the synergistic action between beta-cyclodextrin (βCD) and microfibrillated cellulose (MFC). Here, carvacrol (CA), an antibacterial molecule, was incorporated into βCD, which was previously grafted onto the paper substrates by impregnation. The MFC suspension was coated on the ensued substrate surface using a bar-coating process. Due to the presence of citric acid, the grafting process drastically damaged the mechanical properties of the paper substrate, but the air resistance was significantly improved. In the study, synergy between βCD and MFC was established, thus paving the way for the development of a promising technology: sustained-release packaging. Due to grafting of βCD, the paper samples remained antibacterial during the course of 14 h compared with 4 and 6 h for the reference and CA-grafted samples, respectively. Food-packaging materials fundamentally contribute to food quality and safety, as they protect the packaged food against the external sources. In this context, the determination of the hygiene status of the packaging material itself is very important (Feichtinger et al. 2015). However, European legislation neither sets any microbiological criteria, nor provides any approved standard for the microbiological testing of food-packaging materials. Nevertheless, reliable routine control is essential for ensuring the hygiene attribute of the packaging. With the aim to achieve a maximum recovery rate at low-contamination levels, an improved experimental design was developed by Feichtinger et al. (2015). Two different types of paper laminates, a paper—PET laminate (for packaging chilled dairy desserts) and a paper–aluminum laminate (for wrapping chocolate bars) were used as sample materials and were examined for their microbial contamination before and after spiking.

Similarly, starch-, protein-, nano-, and other material-based coatings and, more recently, conducting polymeric coatings, have attracted great attention in the development of new functional papers and packaging materials for their applications as antistatic and electromagnetic-shielding papers, novel wall coverings, electrical-resistant heating papers, and antibacterial papers (Youssef et al. 2012). Most often, polypyrrole (PPy) is preferred as a conducting polymer for fibre coating because of its positive attributes of low toxicity, chemical stability, and easy commercial availability. Further, polyaniline (PANi), another type of well-known conducting polymer, is characterized by its highly p-conjugated polymeric chain, metal-like conductivity, reversible chemical properties, and different morphology as well as electrochemical and physical properties in doping/de-doping process. This has led to the development of many promising end applications. Such coatings can be incorporated into pulp using more than one method, however, the most popular one is the in situ polymerization of a monomer. In addition, the influence of pulp type and the content of acidic groups (e.g., sulfonic or carboxylic groups) was studied. The kappa number (e.g., the residual lignin content) of unbleached kraft pulp and the beating degree of bleached kraft pulp on the conductivity of PANi-coated paper were also studied (Qian et al. 2010). It was found that the amount of PANi coating increased with increasing content of sulfonic groups or decreasing kappa number of the unbleached kraft pulp. Youssef et al. (2012) reported the development and properties of conductive paper based on cellulosic raw materials from unbleached bagasse and/or rice straw fibers. The hybrid materials can be included in other materials such as plastics, surface coated and anti-static packaging materials or anti-bacterial papers. It was observed that the electrical conductivity (S cm^{-1}) increased profoundly from 8×10^{-13} in the untreated rice straw sample to 2.5×10^{-5} in the 10 % PANi-treated sample. With the increasing application of PANi, the conductivity was found to improve, and a similar trend was also observed in the bagasse sample. However, the breaking length, burst factor, and tear factor were found to decrease with the increasing ratios of PANi added.

Gallstedt and Hedenqvist (2006) investigated different ways of imparting the barrier component at an early stage of the paper-making process to explore the possible synergistic effects of mixing pulp fibers and chitosan in terms of the barrier properties of the sheet and the buffering-induced shrinkage. Paper-making processes were simulated either by using a laboratory paper machine or by solution-casting sheets in Petri dishes. Chitosan–acetic acid salt agglomerated with the pulp fibers and the sheet homogeneity increased during the pressing after sheet formation. The most homogeneous sheets were obtained by solution-casting in the Petri-dish system. At chitosan solution contents >50 wt%, a sufficiently continuous chitosan–acetic acid salt phase was formed, which led to the formation of a sheet with low oxygen permeability. The shrinkage during the buffer treatment could also be effectively reduced due to the presence of pulp fibers. The natural self-assembled micro-structured particles (diatomaceous earth) were used to develop a gas sensor paper with a detection mechanism based on the changes in visible and distinct colour of the sensor paper when exposed to volatile basic nitrogen compounds (Hakovirta et al. 2015). The coating formulation of the paper was prepared by applying diatomite polyvinyl alcohol (PVOH) and pH-sensitive dyes on the acidic paper substrate. The surface coating was designed in such a way as to allow maximum gas flow through the diatomite sensors. The prepared sensor paper, when tested for sensitivity using different ammonia concentrations, exhibited a lower sensitivity limit of 63 ppm.

5.3 Corrugated Boxes in Packaging

Cardboard boxes are industrially prefabricated and primarily used for the packaging of goods and materials. Specialists in the industry seldom use the term "cardboard" because it does not denote a specific material.[15] Corrugated box, a machine-shaped paperboard container with a hollow structure, has been extensively accepted in the packaging and transportation of various goods owing to its advantages of light weight, low cost, ease of assembly and disassembly, good sealing performance, cushioning and antivibration properties, easy recovery behaviour, and amenability to waste treatment (Chen et al. 2011). Their popularity is also due to their good stacking strength in a dry state, easy of availability, and lower cost. Unlike other types of packaging materials, these kinds of boxes protect the packed material from mechanical damage due to drops, impacts, vibration, and compression loads (Pathare and Opara 2014). Corrugated boxes have been extensively used for the transportation and storage of fresh produce in the horticultural industry. Corrugated board has many specific advantages such as low mass (saves money when transporting), easily customizable, strong and stiff, easy to handle, easy to print, and recyclable. Paper and board (38 %) is the mostly used consumer packaging, followed by usage of plastic (30 %), since 1903, when the corrugated box was first accepted by legal freight classification organizations as the containers suitable for freight transportation. China introduced the use of the corrugated box as the external packaging box in the early 1930s. At that time, 80 % of external packing boxes in use were from wooden boxes with cartons accounting for only approximately 20 % of packaging. However, use of corrugated boxes penetrated the market, and by the end of 1940 the percentage of these boxes in use reached to 80 %. Currently approximately 90 % of packing boxes in use are made of corrugated boxes due to technological development in packaging materials and machines. Mainly five different types of corrugated boxes can be produced by various optimal combination of raw materials: (1) lightweight corrugated box, (2) high-strength corrugated honeycomb composite board, (3) intensified sandwich-corrugated cardboard, (4) four-layer corrugated cardboard, and (5) network-structured corrugated cardboard (Chen et al. 2011). A corrugated roll is made of crepe paper, tissue paper, paper boards, plastic films, and many other fibres (see Footnote 15). These products are also widely used for the packaging of products such as plastic ware, glass ware, and steel utensils.

It may be noted that corrugated boxes are predominantly used for export items, whereas reusable plastic containers (RPC) are mainly used in the domestic market. The analysis and prediction of the stacking compression-load capacity of corrugated boxes is important and was studied in detail by Pathare and Opara (2014) to analyze the response of the existing packaging to mechanical stress or to design entirely new boxes to meet postharvest handling conditions. Finite-element analysis and simulation were found to be useful to study and structurally design ventilated corrugated packaging considering the shape, location, and size of the vent. Zhang et al. (2011) described the use of corrugated cartons in packaging low-temperature yogurt with a focus on hazard factors of its external packaging cartons in the logistics process. On the basis of production, storage, and transportation of yoghurt, the factors investigated in their study were relative

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[15] http://www.corrugatedboxess.com/corrugated-boxes.html, dated 22-05-2015.

humidity of the storage environment, stock time, storage and stacking, circulation, transportation, handling, and loading and unloading procedures. Similarly, the hazard factors and degree of hazard encountered in each logistics link were also analyzed and summarized.

The most suitable material for packaging fruits and vegetables are wooden and corrugated fibre board (CFB) boxes made of wood pulp and polyethylene films. By considering the requirement of packaging material today, it is not possible to meet such a demand of timber (wood pulp) from the existing forest coverage without causing major ecological imbalance. The use of CFB boxes in India is limited due to the higher cost of forest-based raw materials. However, it is possible to considerably lower the cost of production of CFB boxes by using agricultural and horticultural fibrous or nonfibrous biomass such as cotton plant stalks, jute plant stalk, pineapple leaves, banana pseudo stem, sisal fibres, etc., which are available abundantly from eco-friendly and renewable sources and are not effectively used for other high-valued applications. The current availability of agricultural biomass in India is estimated to be approximately 120–150 million MT including the agricultural and forestry residues. Using these agricultural biomasses to make CFB boxes has an economically viable potential opportunity while preserving the existing forest coverage. Advancements are continually taking place in developed countries pertaining to both the material as well as the art of packing due to the availability of high quality, soft-wood raw material. Among developing countries, China has already been quite successful in the utilization of cotton stalk for manufacturing of CFB boxes. Large amounts of corrugated paper rolls made of crepe paper, tissue paper, paper boards, plastic, films and many other materials are presently used as a biodegradable packaging of plastic ware, glassware, and steel utensils. This kind of specialty single-, double-, triple-layered and composite papers also find application in industries such as food processing, stationery, textiles, plastic, and processed foods, e.g., bakery, confectionery, and breads, due to their positive attributes of high flexibility and smooth finishing. Corrugated rolls are also available in different lengths and colors to fulfill the specific demands of customers.

6 Biodegradable Polymer/Film and Bio/Nanocopmosite for Packaging

6.1 *Biodegradable Polymer or Film*

The current global consumption of plastics is >200 million tonnes with an annual growth of approximately 5 %, thus representing the largest field of application for crude oil. In the last two to three decades, the production and application of plastics, such as PET, PVC, PE, PP, PS, and PA, have increased exponentially worldwide as packaging materials due to their characteristic advantages of availability in large quantity, low cost, good tensile and tear strength, and good barrier properties to oxygen, carbon dioxide, anhydride, and aroma compounds, heat-sealability, thermoplasticity, and inertness (Vigneshwaran et al. 2011). However, so far with the progress of time, waste disposal and management has become a concern, and the situation has worsened because the packaging materials are not biodegradable. As a result, research has intensified on the development of plastics that degrade faster in the environment, thus leading to a complete mineralization or bioassimilation of the plastics (Avella et al. 2005). At present, biopolymers are getting attention regarding those applications where biodegradability and/or the derivation of natural resources is an added value, particularly where valuable petroleum-based plastics are used for applications with a short lifetime. The biodegradable material can be used as a packaging material, such as a shopping bag, which has a shorter lifetime application and where the recycling is either difficult or not economical or both. The term "biodegradable" material is used to describe materials that can be degraded under specific environmental conditions by the enzymatic action of living organisms such as bacteria, yeasts, fungi. The ultimate end products of the degradation process would be CO_2, H_2O, and biomass under aerobic conditions and hydrocarbons, methane and biomass under anaerobic conditions (Avella et al. 2005; Mensitieri et al. 2011). According to the European Bioplastics, biopolymers made from renewable resources must be biodegradable and, especially, compostable so that they can act as fertilizers and soil conditioners at the end of their service life. At present, there is a considerable demand to replace partially or fully synthetic plastic with biodegradable polymers. In this regard, some of the bio-natural polymers such as aliphatic polyester (polycaprolactone) and polylactic acid, have been attempted as packaging materials, but they have not been commercially successful due to their higher cost compared with competitive petrochemical-based polymers. For the sake of simplicity, biodegradable polymers derived from renewable resources are called "biopolymers" in food packaging and for other applications. Currently, biodegradable plastic represents just a tiny market compared with conventional petrochemical-based plastic due to their higher price. Among various biomaterials derived from renewable sources, starch-based products are the most widespread and economically feasible (Avella et al. 2005). To engineer the physicochemical properties of plastics obtained from various renewable resources to improve/meet certain processing requirements and functional and structural demands, several chemicals and additives have been developed to be added to the polymer, e.g., stabilizers, antioxidant, plasticizers, fillers, and processing aids (Mensitieri et al. 2011). Biodegradable polymers can be broadly classified into three groups, namely,

- polymers directly extracted or removed from biomass such as polysaccharides and proteins
- polymers produced by classical chemical synthesis starting from renewable bio-based monomers, such as polylactic acid (PLA), and
- polymers produced by microorganisms or genetically modified bacteria such as polyhydroxyalkanoates, bacterial cellulose, xanthan, and pullulan.

Brief details of some of the best known biodegradable polymers are reported below.

Polylactic acid (PLA): PLA is one of the current versatile biodegradable polymers whose properties, such as the degree of crystallinity, melting, and glass transition temperature, can be tailored by controlling the L and D isomeric forms. The structural, thermal, crystallization, and rheological properties of PLA as well as the specific mechanical processes, such as extrusion, injection molding, injection stretch blow molding, casting, blown film thermoforming, foaming, blending, fibre spinning, and compounding, have been reported in the literature in detail (Mahalik and Nambiar 2010; Lim et al. 2008). PLA shows much lower barrier properties than the well-known polyethylene terephthalate (PET) and it is difficult to heat-seal. However, these challenges could be overcome by blending PLA with other polymers by using micro and nanocopmosites, by coating it with high-barrier materials, and by polymer modification. At present, it is possible to produce plastic shopping bags from polylactic acid (PLA), a biodegradable polymer derived from lactic acid, a vegetable-based bioplastic (Shah et al. 2008). This material biodegrades faster under composting conditions and does not leave a toxic residue.

Cellulose: Cellulose is extracted chemically by isolation from its crystalline state in microfibrils. It is fusible and soluble in hydrogen bond-breaking solvents such as *N*-methylmorpholine-*N*-oxide. Under normal conditions, because of its infusibility and insolubility to others, its derivatives have been explored for packaging applications (Mahalik and Nambiar 2010).

Protein based film: Several protein sources have been proposed for the preparation of new thermoplastics. Protein-based films can also act as barriers to oxygen, carbon dioxide, and oil and fats, which are the important desirable properties of a packaging material. On the other hand, their mechanical and water-vapor barrier properties are generally inferior to those of synthetic-originating materials (Mensitieri et al. 2011). Among the various proteins suitable for film formation only zein, a prolamine from corn, has been extensively studied for research and industrial applications owing to its unique hydrophobic characteristic due to the presence of high content nonpolar amino acids. Zein possesses a substantially better moisture-barrier property than any other proteins such as casein or polysaccharides such as starch.

Poly-beta-hydroxyalkanoates (PHB): PHB, a member of poly hydroxyl alkanoates, degrades in the presence of various microorganisms that in contact of polymer secrete enzymes, which is responsible for breaking the polymer into smaller parts (Sorrentino et al. 2007). The PHB is 100 % resistant to water, biodegradable, and thermoplastic in nature. Typically, it is a highly crystalline thermoplastic with very low water-vapor permeability akin to the low-density polyethylene (LDPE). However, it suffers from a major drawback of unfavourable ageing process during application.

Polyhydroxy-co-3-butyrate-co-3-valerate (PHBV): Among the matrices used for the preparation of biocomposites. PHBV, a bacterial aliphatic copolyester, has been reported to be produced from by-products of the food industry, and it possess the complete biodegradability during composting, backyard, or landfill conditions, and/or recyclability (Berthet et al. 2015). It could be easily processed through extrusion or injection. It displays a high water-barrier property and has acceptable mechanical properties despite of tendency toward brittleness. However, it is still costlier for food-packaging applications; in addition, its barrier properties are not sufficient enough for fresh foods such as cheese, fruits, or vegetables that require respiration packaging.

Starch polymer: Starch is a semi crystalline polymer stored in granules in most of the plants. It is composed of repeating 1,4-α-D glucopyranosyl units of amylose and amylopectin. Whereas the amylose is almost linear in which the repeating units are linked by α–(1–4) linkages, the amylopectin has α–(1–4)-linked backbone with 5 % of α–(1–6)-linked branches. The relative amounts of amylose and amylopectin depend on the plant source. The ratio of the two components characterises the different properties of the material. For example, corn starch granules typically contain approximately 70 % amylopectin and 30 % amylase (Mahalik and Nambiar 2010). In the food-packaging application, starch-based material has received considerable attention due to its advantages of biodegradability, low cost, renewable in nature, thermoplasticity, and wide availability at a much lower cost (<1 euro/kg) (Vigneshwaran et al. 2011; Avella et al. 2005; Mensitieri et al. 2011). Biodegradation of starch-based polymers occurred due to enzymatic attack at the glycosidic linkages between the sugar groups, which leads to a reduction in chain length and splitting out into lower molecular-weight sugar units (Mahalik and Nambiar 2010). This holds great promise for application in packaging as an alternative to synthetic nonbiodegradable polymers. It may be noted that starch, as a packaging material alone, does not form films with adequate mechanical properties until and unless it is first plasticized or chemically modified. Additionally, it is still not being used to its fullest potential due to the limitation of possessing strong hydrophilicity, poor moisture barrier, high brittleness, and inadequate mechanical properties (Azeredo 2009).

6.2 Reinforcement of Biodegradable Polymer

As described earlier, the use of synthetic petrochemical based polymers, such as PET, PVC, PE, PP, PS and PA, has been partially restricted because they are not fully recyclable and/or biodegradable and hence pose a serious threat to ecology (Vigneshwaran et al. 2011). Awareness of the waste-disposal problem and its impact on the environment has created a new interest in the area of degradable polymers (Shah et al. 2008). Several natural polymers—such as cellulose, starch, lignin, and chitosan (carbon-based polymers)—are biodegradable and compostable. Despite several technological interventions in biopolymers for eco-friendly food packaging, their utilization has still not reached their full potential due to poor mechanical and barrier properties and greater cost. These limitations have recently been partially addressed by incorporating micron- to nano-sized reinforcing ingredient (fillers) during composite preparation. The poor barrier to gases and vapors and poor mechanical properties of biopolymers have led to newer research and development (R&D) in improving these properties. R&D in polymeric materials, appropriate fillers, matrix and filler interaction, and new formulation strategies to develop composites have potential opportunities in food-packaging application (Majeed et al. 2013). Polymer composites are mixtures of polymers with inorganic or organic additives having certain geometries such as fibres, flakes, spheres and particulates. Natural fibres as bio-fillers have been the preferred choice because they exhibit advantages such as low cost, low density, reduced tool wear, and acceptable specific strength in addition to their renewable and degradable characteristics. In most cases, bio-fibres are cheaper than synthetic fibres and cause fewer health and environmental hazards compared with glass fibre-based composites. This may lead to the production of highly durable consumer products from natural fibres that can be easily recycled. Polyhydroxy-co-3-butyrate-co-3-valerate (PHBV) is a completely biodegradable matrix used for the preparation of biocomposites. However, it has an inadequate barrier property, an important requirement in respiring packaging, but it was improved by the addition of other fibres. Berthet et al. reported the impact of wheat-straw fibre size, morphology, and content on the mechanical properties and water-vapour permeability of PHBV-based composite materials (Berthet et al. 2015). Three types of wheat-straw fibres varying in diameter of 17, 109, and 469 μm were used. Based on the various analyses, it was postulated that the new range of PHBV-based composites with tunable properties could be developed successfully as per the requirements of respiring fresh-food products such as strawberries, thus enabling to preserve them in a better way compared with the current use of polyolefins.

In the process of manufacturing biodegradable packaging materials, many functional as well as reinforcing additives are used to improve their physical, mechanical, barrier, thermal, and functional properties. In this regard, it has been observed that incorporation of PLA isomers, sodium caseinate, and whey protein decreases the glass-transition temperature of the polymer and increases tensile strength and puncture resistance. Similarly, zein, a major component of corn protein, has become an important industrial material providing biodegradablity as well as good tensile and water-barrier properties. In addition, zein in nano-form, such as nanobeads or nanoparticles, can be used as edible carriers for flavor compounds or for the encapsulation of nutraceuticals as well as to improve the strength of plastic and bioactive food packages.

6.3 Nanocompsite and Biocomposite for Packaging

In the last decade, due to the rapid growth of nano-science and nanotechnology, it has been proven that the application of organic/inorganic nanomaterial as filler could enhance the mechanical and barrier properties of various nanocopmosites. The applications of nanotechnology in the agriculture and food sectors are relatively recent compared with their use in drug delivery and pharmaceuticals (Sozer and Kokini 2009). The application of nanotechnology in polymers may open new possibilities for improving not only their properties but also their cost-efficiency

(Azeredo 2009). In this context, it is worth mentioning that the application of organic and inorganic nanomaterials (e.g., clay, silica, cellulose, chitosan, starch nanocrystal, zein-nano beads, TiO_2, and silver) in film or matrix (e.g., starch, carrageenan, cotton seed protein, and soya protein) has shown improvement in mechanical, thermal, gas-barrier, antimicrobial activity, enzyme immobilization, biosensing, oxygen scavenging properties, etc. (Azeredo 2009; Sozer and Kokini 2009). The common plasticizers for hydrophilic polymers are glycerol, polyether, urea, and water. Starch as a film or bag could be employed in packaging fruits and vegetables, snacks, or dry products (Savadekar and Mhaske 2012). Efficient mechanical, oxygen, and moisture protection is desirable in such applications. Thermoplastic starch (TPS) alone often cannot satisfy all these requirements because its hydrophilic nature that likely causes change in thermoplastics' performance during and after processing due to changes in the water content. In addition to the improvement in mechanical and barrier properties of the packaging materials due to the incorporation of nano-fillers, various nano-structures are also responsible for providing active or "smart" properties, such as antimicrobial activity, enzyme immobilization, biosensing, etc., to the packaging system (Azeredo 2009). The use of nano-scale fillers leads to the development of polymer nanocomposites with improved tensile modulus, dimensional stability, and resistance to solvent or gas. Such composites also possess additional benefits such as low density, transparency, good flow, better surface properties, and recyclability by the addition of a filler (Sorrentino et al. 2007). The massive effort to extend shelf life and enhance food quality while reducing packaging waste has encouraged exploration of new bio-based packaging materials such as edible and biodegradable films from renewable resources (Sorrentino et al. 2007). Also, the quality of packaged food is directly related to the attributes of food as well as the packaging material. Most of the food's qualities become deteriorated due to mass-transfer phenomena such as moisture absorption, oxygen invasion, flavor loss, undesirable odour absorption, and migration of packaging components in the food (Galic et al. 2011). The phenomena can occur between the food product and the surrounding atmosphere, i.e., between the food and the packaging materials, or among the heterogeneous ingredients in the food product itself. Thus, the rate of transport of such reactants across the partial barrier of the package wall can become the limiting factor in the shelf life of the packed food. To increase the shelf life of processed foods, the package must be designed in such a way as to have adequate water-vapor (WV) and/or gas (O_2, CO_2, etc.) permeability. The use of nanocomposites in food packaging is attracting considerable interest due to their many fascinating features as discussed below (Majeed et al. 2013).

(i) ***Nano cellulose and its starch based composite***

Though the use of plastics in food packaging and agriculture is essential, plastics have simultaneously adverse medium to long-term effect in polluting soil, food and the environment. On the other hand, indeed many of the available alternative biopolymers, such as starch and k-carrageenan, cannot compete techno-mechanically with the well-established synthetic counterpart due to their inadequate mechanical and barrier properties (National Agricultural Innovation Project 2012). Presently, nonspinnable short cotton fibres and cotton linters, being a major source of cellulose and ubiquitously available in India, has found application in the production of microcrystalline cellulose, cellulose powder, and cellulose acetate to be used as filler in nanocopmosites and other high-value, low-volume applications. Cellulose is one of the most important, abundant, renewable, and biodegradable natural polymers and it exists in the biomasses of several plants, such as wood, cotton, hemp, straws, sugarcane bagasse, and other plant-based materials. It has a wide range of applications in the form of fibre, paper, films, and polymers. The utilization of such natural biomass in novel applications has recently attracted the global interest due to its ecological and renewable characteristics (Li et al. 2012). Basically two types of nano-reinforcements, such as microfibrils and whiskers, can be obtained from cellulose. In plants or animals, cellulose chains are synthesized to form microfibrils (or nanofibres), which are bundles of molecules held together through hydrogen bonding (Azeredo 2009). Depending on their origin, microfibrils have nano-sized diameters of 2–20 nm and lengths in the micrometer range. Each microfibril is formed by an aggregation of elementary fibrils made of crystalline and amorphous parts. The crystalline parts isolated by different treatments are called "whiskers," also known as "nanocrystals," "nanorods," or "rod-like cellulose microcrystals," and have a high aspect ratio with a diameter of ≤ 8 to 20 nm and lengths ranging from 500 nm to 1–2 μm. In general, nanocrystals of cellulose with diameters ranging from 2 to 20 nm and length ranging from 100 to 2.1 μm (more precisely <100 nm for defect free-crystal) have different names in the literature such as "cellulose nanowhiskers," "cellulose whiskers," whiskers, "nanowhiskers," "nanofibrils," "nanofibres," "cellulose crystallites," "cellulose crystals," "cellulose nanocrystals," "nanocrystalline cellulose," "cellulose monocrystals," and "cellulose microcrystals." These are possible to produce from cotton linters as well as many other natural fibrous agro-biomass (Morais et al. 2013; Cherian et al. 2011; Neto et al. 2013). Over the years, due to the advancement in nano-science and technology along with nano-scale characterization techniques, attempts have also been made to produce microcrystalline cellulose, nanocellulose particles, and nanocellulose fibres to be used as a reinforcing agent in different nano-/bio-composites due to their unique advantages of superior physical properties and environmental benefits such as large specific surface area (estimated to be several hundreds of $m^2\ g^{-1}$), very high modulus of elasticity ($\approx$150 GPa), and high aspect ratio, thus ensuring high strength with low-filler loading, low density ($\approx$1.56 g/cm^3), nonabrasive and nontoxic nature, biocompatibility, biodegradability, and being produced from renewable agro biomasses at a lower cost (Azeredo 2009; Neto et al. 2013). They can also be used as reinforcements for adhesives, components of electronic devices, biomaterials, foams, aerogels, and textiles (Morais et al. 2013). In the literature, a number of approaches have been reported for the production of highly purified nanocellulose from various cellulosic to ligno-cellulosic biomasses such as cotton linter, cotton fibre, sugarcane bagasses, pineapple leaf, soy hulls, and corncob (Li et al. 2012; Morais et al. 2013; Cherian et al. 2011; Neto et al. 2013; Silverio et al. 2013; Santos et al. 2013; Rosa et al. 2010; Haafiz et al. 2014). The methods included are steam-explosion treatment, acid or alkaline hydrolysis, enzyme-assisted hydrolysis, microbial process, high-pressure homogenization, as well as a combination of two or several of the aforementioned methods.

Vigneshwaran et al. reported the production of nano-cellulose by microbial, enzyme and mechanical process consisting of refinement and homogenization, and a comparative assessment was also made between such processes (National Agricultural Innovation Project 2012). The same research group reported the application of nanocellulose as a reinforcing agent in starch film. It was observed that due to its high surface energy as well as high hydrophilic characteristic, nanocellulose tends to aggregate during film formation. This problem was addressed by the addition of gum arabic to assist in the uniform distribution of nanocellulose. The nanocellulose–starch film was prepared by using a soluble starch derived from potatoes by acid hydrolysis to a consistent molecular weight. The film-forming solution was prepared by gelatinizing the starch (4 %) at 95 °C followed by the addition of 0.02 % sodium azide and 0.5 % glycerol antimicrobial and plasticizing agent. In the composite-film preparation, the nanocellulose add-on was kept at 1 % of the weight of starch. In an alternative method, a solution-cast film of k-carrageenan was prepared using 0.1, 0.2, 0.3, 0.4, 0.5, and 1 % nanocellulose fibres using distilled water as the solvent. A similar sample of k-carageenan was also prepared in the presence of nano-cellulose instead of nanocellulose fibres. The physical and mechanical properties of starch-nanocellulose composite are reported in Table 5.

Similarly, Savadekar and Mhaske (2012) reported the improvement in mechanical properties of starch films by the incorporation of nanocellulose fibres (NCF). The NCF were successfully synthesized from short staple cotton fibres by a chemo-mechanical process, and its composite with thermoplastic starch (TPS)

Table 5 Different properties of biodegradable starch films (Vigneshwaran et al. 2011; Avella et al. 2005; National Agricultural Innovation Project 2012)

Different film	Tensile strength (MPa)	Elongation at break (%)	Thickness (µm)	Surface energy (dyne/cm)	WVTR (g/m^2h^1)	Solubility (%)
Control starch film	1.35 ± 0.8	20.2 ± 2.5	140 ± 2	40.5 ± 2.5	388 ± 15	39.5 ± 0.5
Starch + nanocellulose	3.27 ± 1.1	22.8 ± 2.9	150 ± 2	28.7 ± 2.3	265 ± 13	35.7 ± 1.7
Starch + nanocellulose + gum arabic	4.79 ± 1.3	36.6 ± 3.8	150 ± 2	21.2 ± 2.2	181 ± 10	32.1 ± 0.5
	Stress at peak (MPa)	Elongation at break (%)	Young modulus (MPa)			
Starch	19	3	979			
Starch + clay (4 %)	22	4	1135			

WVTR Water vapor transmission rate

was prepared by solvent-casting method. The 0.4 wt% NCF-loaded TPS films showed 46 % improved tensile strength compared with the base polymer film, but beyond 0.5 wt% the addition of NCF was found not to be beneficial because the tensile strength started to deteriorate. Oxygen permeability was found to decrease significantly, i.e., by 93 % in the 0.4 % NCF/TPS sample compared with the control TPS sample, possibly due to increased tortuous pathways used for the permeation of oxygen molecules in the presence of NCF in starch film. Similar result were also observed in the water-vapor permeation rate. In a similar experiment, the moisture barrier of polymer films was observed to improve owing to an increase in the tortuosity in the materials, thus leading to slower diffusion processes and hence lower permeability (Azeredo 2009). The barrier properties are expected to enhance if the filler with a high aspect ratio is uniformly dispersed in the matrix. It was seen that the incorporation of nanocellulose as a filler could increase the tensile strength of starch film by 3.5 times. A similar result was also observed in a water-vapour permeability test where permeability was found to decrease by 2 times (Vigneshwaran et al. 2011). It was also observed that oxygen permeability was decreased by 93 % in the case of a nanocomposite film compared with a control starch film. Figure 4 shows the packaging of strawberries and broccoli in a starch/nanocopmosite film. In the biodegradability study, the starch–nanocellulose composite film was found to degrade in 21 days by the native microbial population in garden soil. From the above-mentioned observations, it can be inferred that this kind of composite film may be suitable for food packaging and agricultural field-mulching applications.

Similar to the application of starch/nanocellulose fibre/particle or starch/clay composite film, Savadekar et al. (2012) reported a structure-property evaluation of kappa-carrageenan (KCRG) and nano-fibrillated cellulose (NFC) composite film for application in food packaging. Carageenan is a water-soluble linear

Fig. 4 Packaging of strawberries and broccoli in starch–nanocellulose composite film (National Agricultural Innovation Project 2012)

polymer (polysaccharides) extracted from red seaweed and extensively used in foods, cosmetics, and pharmaceuticals. This particular film has the advantages of good transparency, tensile strength, gelling ability, and film-forming capability. However, it suffers from higher cost, poor barrier properties, and lower tensile-breaking elongation. Carageenan as edible films and coatings has already been used in the food industry for the packaging of fresh and frozen meat, poultry, and fish to prevent superficial dehydration and for other purposes. The NFC was prepared from short staple cotton fibres by chemo-mechanical process in a laboratory disc refiner. The diameter of fibril under SEM was estimated to be 242 ± 158 nm. It was seen that the tensile strength of KCRG increased with increasing NFC loading up to 0.4–0.5 wt% followed by a decrease. Similarly, the 0.4 % nano-fibrillated cellulose showed the lowest water-vapor and oxygen-transmission rates, i.e., approximately 80 % reduction compared with the control film (Savadekara et al. 2012). In 1993, LDPE-starch blends were commercialized under the trade name Ecostar (Siracusa et al. 2008). Other commercial trade names of LDPE-starch blends are Bioplast® (from Biotec GmbH) and NOVON® (from NOVON International) (Siracusa et al. 2008).[16] Salehudin et al. reported the development of a starch–chitosan hybrid film that is totally degradable because it is produced from a renewable material. Its low mechanical properties were improved by the addition of oil palm empty fruit bunch (EFB) cellulose nano-fibres (Salehudin et al. 2014). The role of chitosan in the starch film packaging was to ensure the killing of pathogens (antimicrobial) and hence to increase food shelf life. Transmission electron microscopy (TEM) images showed nanofibre diameters in the range of 1 to 100 nm. Nanocopmosite film was constructed by keeping the cellulose nanofibre content, constant at 2, 4, 6, 8, and 10 % weight of the starch. The tensile strength of the control starch–chitosan film was 3.96 MPa, and it was increased to the highest value of 5.25 MPa in the 8 % nanocellulose-incorporated sample. The antimicrobial efficacy result showed that the addition of cellulose nanofibre could increase the inhibition effect toward gram-positive bacteria but not toward gram-negative bacteria.

Dogan and McHugh (2007) reported that microcrystalline cellulose (MCC) with submicron-size diameters had a much higher effect on tensile strength in hydroxyl propyl methyl cellulose (HPMC) than their micron-sized MCC counterpart Additionally, the negative impact of the micron-sized MCC on the elongation of the films was much more noticeable than that of its submicron-sized counterpart. Nanocomposites of pea starch matrix with cellulose whiskers extracted from pea hull fibers have also reported. The composite showed the highest transparency and the best tensile properties when they were produced from whiskers with the highest aspect ratio (Chen et al. 2009). The thermal stability of the polymers in nanocomposites with cellulose whiskers was reported to be greater than those made from corresponding bulk polymers (Azeredo 2009).

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[16] www.designinsite.dk, dated 22-05-2015.

(ii) ***Starch and various nanofiller-based composite***

The main challenge of preparing nanocopmosites is the uniform dispersion of nanofiller and in the present case, nano-clay in the biopolymer matrix. Montmorillonite is the most commonly used natural clay that has been successfully applied in numerous nanocomposite systems (Savadekar and Mhaske 2012). Avella et al. (2005) reported the novel biodegradable starch/clay nanocomposite film preparation and their requisite property evaluation to be used as food packaging. The films were made by the casting process using potato-based starch and 4 % purified montmorillonite clay. In some of the films, biodegradable polyester was also added. All of the mechanical properties were evaluated by storing the samples in three different relative humidity conditions to correlate the effect of different moisture conditions during storage and the influence of water presence on the final performance of the films. It was clearly observed that the presence of clay profoundly increases the young modulus of the starch film at all the humidity conditions under the experiment. On the other hand, the film samples to which biodegradable polyester was added showed a decreases in young modulus irrespective of the humidity conditions. At low humidity, the samples showed better mechanical properties. It seems that water strongly affects the modulus of the starch blends. In the same study, the researchers also reported the presence of metal particles in the film, which can migrate and come into contact with the food. Therefore, analysis of some vegetables (lettuce and spinach) in contact with the starch-based biodegradable films was performed and no significant increase of iron (Fe) and magnesium (Mg) was found in the vegetables. However, a slightly higher silicon (Si) content was observed, which was possibly due to the presence of clay nanoparticle containing silicone (Avella et al. 2005). Based on the actual regulations and European directives on biodegradable material assessment, starch–clay nanocomposite films can be effectively utilized in the food-packaging sector owing to their low overall migration limit.

The addition of <5 % clay as a filler was done to improving the tensile and elongation properties of thermoplastic starch (Sorrentino et al. 2007). Beside, the decomposition temperature was increased, whereas the relative water-vapor diffusion coefficient of TPS was decreased. Similarly, silica nanoparticles ($nSiO_2$) have also been used to improve the chemical and/or barrier properties of several polymer matrices. In this regard, the improvement in tensile properties was reported for a starch matrix due to incorporation of $nSiO_2$ (Azeredo 2009). To increase the barrier properties of zein polymers, it was modified with stable silicate complexes of montmorillonite, hectorite and saponite of 1 nm in thickness, with diameters ranging from 30 to 2000 nm to improve their strength and stiffness, and water and gas permeability, even at low levels of 1–5 vol.% application (Yoshino et al. 2002).

(iii) ***Other nanocopmosites***

It is interesting to note that not only starch can be used as a matrix in biodegradable film formation, it can also be used in nanoparticulate form to improve various physico-mechanical properties of different composite materials (Azeredo 2009; Mensitieri et al. 2011). Native starch granules can be submitted to an extended-time hydrolysis at temperatures below the gelatinization temperature, thus enabling the hydrolysis of amorphous regions and resulting in the separation of crystalline lamellae, which are more resistant to hydrolysis. Starch crystalline particles show platelet morphology with thicknesses of 6–8 nm. It has been reported that the tensile strength and modulus of pullulan film can be enhanced by the addition of starch nanocrystal (Azeredo 2009). The water-vapor permeability of pullulan films was decreased by the addition of ≥20 % of starch nanocrystal. In a similar vein, the preparation of chitin/chitosan nanoparticles, 500 nm in length and 50 nm in diameter, has been obtained by acid hydrolysis of chitin. Lu et al. incorporated chitin whiskers into soy protein isolate (SPI) thermoplastics, and it was observed that the whiskers greatly improved the tensile strength, elastic modulus, and water-resistance properties (Lu et al. 2004). Zein, a prolamin and the major component of corn protein, has recently been an important material for food-packaging applications owing to its unique properties. Biodegradable zein films with good tensile and water-barrier properties were prepared by dissolving zein in either ethanol or acetone (Sozer and Kokini 2009; Yoshino et al. 2002). Zein nanobeads or nanoparticles can also be used as edible carriers for flavor compounds or for the encapsulation of nutraceuticals as well as to improve the strength of plastic and bioactive food packages (Sozer and Kokini 2009). Similarly, silicates consisting of crystalline layers with 1-nm thickness and diameters ranging from 30 to 2000 nm in nanocomposites are able to control the gas-diffusion rate through their tortuous pathway.

7 Environmental Implications of Biodegradable Packaging

Because packaging waste constitutes a significant portion of municipal solid waste, it has in recent years heightened environmental concerns, thus leading to the strengthening of EU regulations to reduce the quantum of packaging waste (Davis and Song 2006). A large numbers of oil-based polymers, such as PET, PP, PE, PS, PA, and others, are currently being used in packaging applications. These synthetic polymers are nonbiodegradable and also difficult to recycle or reuse due to their admixture with contamination, complex composites, and the presence of different processing additives such as fillers, dyes/pigments, and plasticisers as well as coating or multilayer composite structure used to enhance the product's aesthetic and functional performance. These altogether pose difficulties in collecting, identifying, sorting, transporting, cleaning, and reprocessing of plastic packaging materials, thus making recycling uneconomical; however, disposal to a landfill is a more convenient alternative. With the recent development in biodegradable packaging materials from renewable natural resources with properties more or less similar to those of synthetic polymers, it is anticipated that biodegradable polymers would contribute toward the development of sustainable packaging materials. Davis and Song (2006) reported the impact of biodegradable packaging materials on waste management in terms of landfill, incineration, recycle/reuse, and composting with respect to oil-based polymer packaging materials. In the study, it was observed that biodegradable packaging materials are most suitable for single-use disposable applications, whereas postconsumer used packages can be locally composted as a means of recycling the materials. Establishment of an appropriate collection, transportation, and treatment technologies are considered crucial for the success of widespread applications of biodegradable packaging materials. Because recycling is energy-expensive, compostability is one of the most important attributes of a biopolymer that allows disposal of the packages in the soil. Approximately 67 million tonnes of packaging waste are generated annually in the EU comprising approximately one third of all municipal solid waste (Davis and Song 2006). In the United Kingdom, 3.2 million tonnes of household waste produced annually comes from packages, which equates to >12 % of total household waste produced. In developed countries, food packaging represents 60 % of all packaging. Low-value soiled packaging films and carrier bags may be used as an economic boiler fuel (i.e., incineration combined with electricity generation) because they are usually manufactured from polyethylene and has a very high calorific value. Biopolymers, such as natural fibres and starches, have relatively lower gross calorific value (GCVs) compared with synthetic polymers. However, GCVs values of the biopolymer are close to those of wood, and thus they are still suitable for incineration. Composting is an essential process to breakdown waste through biodegradation, and this is considered the most attractive route for the treatment of biodegradable packaging waste. Usually biodegradable polymers degrade by the same mechanisms as organic matter within aerobic composting systems. The trigger for degradation could be a microbial, hydrolytically, or oxidative susceptible linkage built into the backbone of the polymer, or, alternatively, additives that catalyze the breakdown of polymer chains. This trigger may be specifically designed so as to ensure that degradation does not occur within the "use lifetime," but it should ensure degradation on disposal within a given environment. Although the incorporation of nanomaterials into polymer/film packaging materials is important, it must be noted that nanomaterials, due to their increased surface area, might have adverse effects on humans and animals (Sozer and Kokini 2009). There might also be potential and unforeseen risks associated with their use in food-packaging materials. Because no regulation that specifically control or limit the production and/or application of nanosized particles presently exists, they must be used very carefully.

Carbon footprint (CF) is a measure of the impact of human activities on earth and the environment. More specifically, it relates to climate change and the total amount of greenhouse gases produced as measured by carbon dioxide emission. Muthu et al. in 2011 reported an exhaustive carbon footprint (CF) analysis of recycled and reused plastic, paper, and nonwoven and woven bags sent to land-filling in countries such as China, Hong Kong, and India (Muthu et al. 2011). The first stage of the study, e.g., the baseline study, showed the impact of different types of shopping bags in the manufacturing phase without considering their usage and disposal. In the next stage, the study of the carbon footprint of these bags, including their usage and disposal phases (i.e., cradle-to-grave stage), was measured. The results showed that high CFs of different types of shopping bags if no usage and disposal options were provided. However, the CF values were lower in the case where a higher percentage of reuse was preferred over recycling and disposing in landfill. It is interesting to note that reuse could significantly scale down the carbon footprint. Once the shopping bags have reached the end of their service life, they must be recycled rather than disposed of in landfill. It has been observed that in India, the greenhouse gas emission was the least (708 g) for the polypropylene nonwoven bag and the greatest (3410 g) for the paper bag. For the functional unit assumed, the nonwoven bags consumed less energy and fewer quantities of materials, and less greenhouse gas is emitted in the production phase of shopping bags compared with its counterparts in China, Hong Kong, and India. Reusable bags, such as nonwoven bags made of polypropylene followed by woven cotton bags, seem to be environmentally friendly compared with conventional plastic and paper bags for the functional unit assumed in the comparative study. In this context, and regarding consumer behavior and governmental policies, it is important to encourage people to choose reusable bags and to promote more recycling systems to scale down the environmental impacts made by any type of shopping bags. In another study, the plastic bag was found to be a little better in terms of environmental impacts compared with paper bags (Muthu et al. 2009).

8 Present Status of Biodegradable Packing

The Indian Packtech segment is expected to grow at a rate of 22 % to USD $11,782 million by 2016 to 2017 as per estimates of the Working Group on Textiles and Jute Industry, Ministry of Textiles, Government of India (see Footnote 9). In India, as per government norms, a minimum of 90 % of food grains and 20 % of sugar total production are to be packed in jute fibre-based hessian and sacking bags. Natural fibre such as jute is suitable for the packaging of sugar and other agricultural food grains due to its advantage of low cost, biodegradability, and being produced from renewable sources. The role of the jute industry in Indian economy is important because India is the largest producer of jute globally and the second-largest exporter of jute goods, which ultimately supports the 40 lakh farm families' livelihood. To develop alternative materials to petrochemical-based nonbiodegradable plastics, in recent years the development of biodegradable packaging materials from renewable natural resources has received widespread government support in EU countries, thus resulting in the establishment of many national or international research organizations to facilitate research and development in this area. Some of these include the European Renewable Resource Materials Association, National Non-Food Crops Centre in the United Kingdom, International Biodegradable Polymers Association and Work Groups in Germany, and Interactive European Network for Industrial Crops Application (Davis and Song 2006). The United Kingdom Government-Industry Forum has also strongly recommended greater use of nonfood crops for biodegradable-packaging applications. The development of biodegradable packaging would ensure utilization of crop over crude oil and integrated waste management so as to reduce landfill. To improve the packaging standards in India, the Indian Institute of Packaging (IIP), a national apex body, was set up in 1966 by the packaging and allied industries and the Ministry of Commerce, Government of India.[17] The other objectives of the institute are to promote an export market by way of innovative package design and development, as well as to upgrade the overall standard of packaging in the country. In addition, the ITC's packaging and printing business is the largest converter of paperboard packaging in South Asia. It converts >70,000 tonnes of paper, paperboard, and laminates per annum into a variety of value-added packaging for foods and beverages, personal products, cigarettes, liquor, and consumer goods.[18] The division that was set up in 1925 as a strategic backward integration for ITC's cigarette business, which is now India's most sophisticated packaging house. State-of-the-art technology, world-class quality, and a highly skilled and dedicated team have contributed to the position of ITC as the first-choice supplier of high value-added packaging materials. Recently microcrystalline cellulose and nanocellulose particles/fibres have become the promising fillers in nano/bio-composite due to their many unique properties as discussed earlier. Vigneshwaran et al. reported the production of nanocellulose by microbial, enzyme, and mechanical processes consisting of refinement and homogenization (Annual Institute Report of Central Institute for Research on Cotton Technology 2013; see Footnote 19). Nanocellulose has been used as a reinforcing agent in a starch-based composite film for packaging and other applications. Now, keeping in mind the future commercial application, the Central Institute for Research on Cotton Technology, Mumbai, India, under the Indian Council of Agricultural Research (ICAR), has already taken a lead role in setting up the nation's first pilot plant for the production nanocrystalline cellulose and nano-fibrillated cellulose from cotton linters and other agro-products by chemo-mechanical and microbial processes with a production capacity of 10 kg/d. The products are intended to be used as filler in polymer composites and other technical applications (Annual Institute Report of Central Institute for Research on Cotton Technology 2013; see Footnote 19).[19]

9 Summary

Packaging materials play an important role in providing protection to goods from physical damage, contamination, and deterioration as well as providing information about the product. It also provides sales appeal, consumer convenience and safety, physical barrier from the external environment such as light, oxygen and humidity, a certain degree of cushioning, and antivibration effects. The use of paper pulp in packaging has become more attractive than the traditional materials,

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[17] http://www.iip-in.com, dated 22-05-2015.

[18] http://www.itcportal.com/businesses/packaging.aspx, dated 22-05-2015.

[19] www.nanocellulose.in, dated on 03-05-2015.

such as expanded polystyrene foam, due to its advantages of low price of the recycled paper, low cost of production, and biodegradability. Such materials have primarily been used for various flexible, semi-rigid, or rigid packaging of electronic items, food, and other products. Similarly, corrugated boxes have been used since the early 1930s as external packing in freight transportation; at present, approximately 90 % of packing boxes in use are made of corrugated boxes. As per government norms, a minimum of 90 % of the food grains and 20 % of the sugar produced in India are to be packed in jute fibre-based hessian and sacking bags. A natural fibre such as jute is most suitable for the packaging of sugar and other agricultural food grains owing to its advantage of low cost, biodegradablity, and eco-friendliness. In addition, jute is also produced from renewable sources and could satisfy the standard for safe packaging. Textile-based packaging, at on end, includes heavyweight, densely woven fabrics (e.g., bags, sacks for storage); on the other end, it includes lightweight nonwoven fabrics used for durable papers, tea bags, shopping bags, and industrial product wrappings. During the past 50 years, synthetic polymers, along with the advancement in polymer science, material science, and packaging technology, have been steadily replacing traditional packaging materials such as paper, glass, metals, fabric, etc. owing to their advantages of low cost, low density, chemical inertness, flexible to rigid structure, and transparency. However, because they are not fully recyclable and/or biodegradable, they pose serious threats to the environment. This fact has led to the development of biodegradable polymers/films such as starch, polylactic acid, protein-based film, and poly-beta-hydroxyalkanoates. Because the majority of such polymers do not possess adequate physical, mechanical, barrier to gas and vapour, and other functional properties, they were engineered by incorporation of micron- to nano-sized filler or reinforcing agents such as silver, titanium dioxide, chitosan, cellulose, clay, starch, silica, and zein protein. In addition, the development of biodegradable packaging materials from renewable natural resources has received widespread government support in EU countries, which has resulted in the establishment of many national or international research organizations to facilitate research and development in this demanding area, which is so closely related to the environment and the very existence of the human civilisation.

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