ISSN: 0379-5462
IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association
Vol. 35, E2, 2023, p. 119-124

REPLACEMENT OF SINGLE USE PLASTIC BY PAPER PRODUCTS IN FOOD PACKAGING – AN OVERVIEW


Dr P. Marimuthu*
General Manager
(R&D and Technical Services)

Ganesh Bhadti*
Director of Operation

**M/s Seshasayee Paper and Boards Ltd,Tamilnadu*

Abstract:

As a global environmental problem, plastic pollution has attracted worldwide attention. Plastic wastes not only disrupt ecosystems and biodiversity, but they also threaten human life and health. Countries around the world have made regulations in recent years to limit the use of plastics. Paper products have been proposed as promising substitutes for plastics particularly in Packaging, which undoubtedly brings more opportunities to the pulp and paper industry. In this paper, types of packaging and comparison between plastic and paper products were discussed. However, paper products have some deficiencies in replacing certain plastic products. Research and development must focus to improve the Coating technology with suitable polymeric material to achieve the required properties of final products and reduce production costs to meet the challenges and it should be more suitable user-friendly barrier coating formulation which has to fulfil the FDA norms and Customers requirement

Keywords: Food packaging, Barrier Coating, plastic and paperboards.

INTRODUCTION:

Packing is a process of building a container or box suitable for a product for transport and storage. Different methods that can be used in packaging are wrapping, cushioning, weatherproofing and sealing. A good packing prevents the product or items from breakage, leakage, pilferage, etc. Generally, the packaging material may either be rigid or flexible. They give physical protection to the food inside which is not provided by flexible packaging. Flexible packaging is a major group of materials that includes plastic films, papers, foil, some types of vegetable fibers and cloths that can be used to make wrappings, sacks and sealed or unsealed bags.

Packaging Materials

Packaging materials play a significant role in how the products reach the consumers. Plastic products have the advantages of light weight, low cost, good ductility, and excellent insulation, which explains why they have been widely used in industry. Over the past few decades, the production of plastics has experienced rapid growth. It is reported that by 2021, production of plastic was 390 million metric tons [1] but collection of plastic waste was only 15% for recycle. The plastic waste has posed a severe and irreversible impact on the global ecosystem and biodiversity. In order to avoid these problems, many countries and regions around the world have successively launched a series of policies and regulations that prohibit and restrict the use of plastic products. At present, materials such as glass, metals, biodegradable plastics, and paper products have been considered as alternatives to plastic products. Among them, paper products have unparalleled desirability of promoting environmental sustainability, since these products are produced from renewable and abundant lignocellulosic biomass, and they have the advantages of recyclability, biodegradability and with lower cost.

Food Packaging

The principal roles of food packaging are to protect food products from outside influences and damage, to contain the food, and to provide consumers with ingredient and nutritional information. Traceability, convenience, and tamper indication are secondary functions of increasing importance. The goal of food packaging is to contain food in a cost-effective way that satisfies industry requirements and consumer desires, also maintains food safety, and minimizes environmental impact. Primary objective of Food packaging is providing protection of physical content of the food product from three major classes of external influences: chemical, biological, and physical, Appropriate physical packaging also protects consumers from various hazards [3,4].

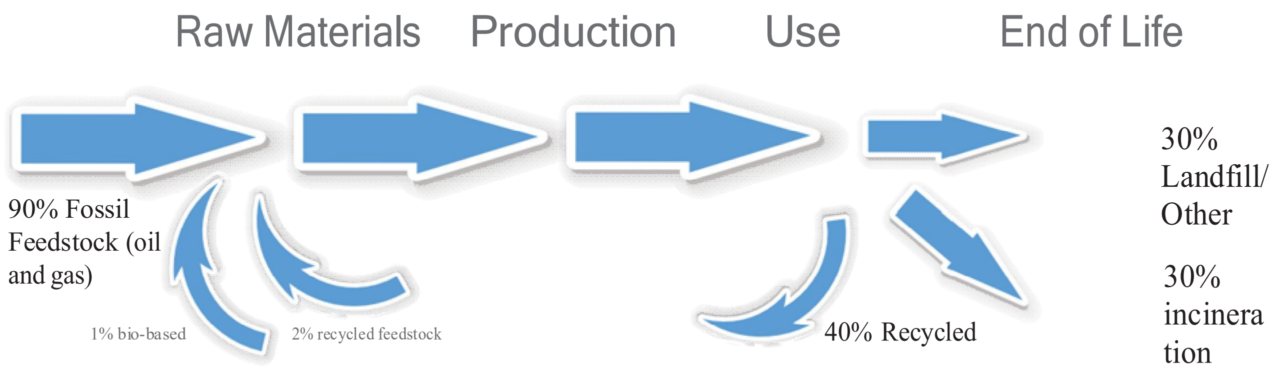
Present scenario

With the implementation of plastic ban, the demand for disposable paper boxes, paper cups, straws, paper bags, paper cans, and other related paper-based products for food packaging are increased, especially during the COVID-19 pandemic period. However, paper products are normally opaque, porous, and not heat-sealed. They have poor barrier performance against oxygen and water vapor. However, such multilayered paper products face recycling problems. Two other popular strategies involve chemical additives, which can be applied either in the course of surface sizing or at the paper machine wet end. However, there are limited options of chemicals for these purposes because of the high safety standards for use in food packaging materials. [5],

Plastic Vs Paper products

The primary raw material for plastic manufacture is oil and gas, which makes up 90% of the feedstock. This is processed through a distillation process into different fractions such as Naphtha, which is further processed into simpler compounds such as ethylene and propylene. These hydrocarbons are then linked together in a chemical reaction called polymerization to form a polymer chain. Different plastics have different polymer chains. The most common plastics used for packaging are 'thermoset' plastics (which soften on heating and harden again on cooling), particularly polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) [6], and to a lesser extent polystyrene (PS) and poly vinyl chloride (PVC). Bioplastics, which can be bio-based derived from plants and it may be account for about 1% of global plastic production. When used as packaging, plastic is claimed to have several benefits, such as flexibility, strength, lightness and impermeability.

Lifecycle overview of Plastics Products

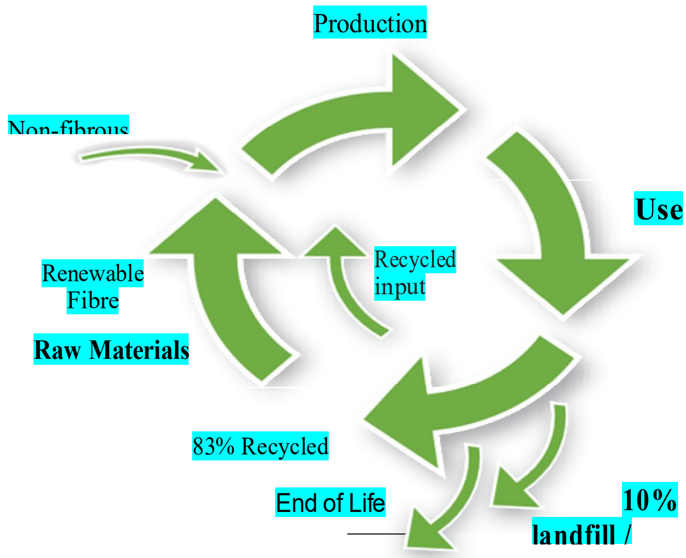


Paper and Paperboards

The use of paper and paperboards for food packaging is accelerated usage in the later part of the 19th century. Paper and paperboard are sheet materials made from an interlaced network of cellulose fibers derived from wood by using sulphate and sulphite process.

The fibers are then washed and bleached and treated with chemicals such as slimicides and strengthening agents to produce the paper product. Paper and paperboards are commonly used in corrugated boxes, milk cartons, folding cartons, bags and sacks, and wrapping paper. Tissue paper, paper plates, and cups are other examples of paper and paperboard product. The primary raw material for paper and board is cellulose fiber, which can either be virgin fibre from trees or recovered fiber obtained from recycling paper products. [7,8]

Life Cycle overview of Paper Products



PAPER PRODUCTS

The following paper products are being used in food packaging.

Kraft paper—Produced by a sulfate treatment process, kraft paper is available in several forms: natural brown, unbleached, heavy duty, and bleached white. The natural kraft is the strongest of all paper and is commonly used for bags and wrapping. It is also used to package flour, sugar, and dried fruits and vegetables.

Sulfite paper—Lighter and weaker than kraft paper, sulfite paper is glazed to improve its appearance and to increase its wet strength and oil resistance. It can be coated for higher print quality and is also used in laminates with plastic or foil. It is used to make small bags or wrappers for packaging biscuits and confectionary.

Greaseproof paper—Greaseproof paper is made through a process known as beating, in which the cellulose fibers undergo a longer than normal hydration period that causes the fibers to break up and become gelatinous. These fine fibers then pack densely to provide a surface that is resistant to oils but not wet agents. Greaseproof paper is used to wrap snack foods, cookies, candy bars, and other oily foods, a use that is being replaced by plastic films. [9]

Glassine—Glassine is greaseproof paper taken to an extreme (further hydration) to produce a very dense sheet with a highly smooth and glossy finish. It is used as a liner for biscuits, cooking fats, fast foods, and baked goods.

Parchment paper—Parchment paper is made from acid-treated pulp (passed through a sulfuric acid bath). The acid modifies the cellulose to make it smoother and impervious to water and oil, which adds some wet strength. It does not provide a good barrier to air and moisture, is not heat sealable, and is used to package fats such as butter and lard.

Paperboard is thicker than paper with a higher weight per unit area and often made in multiple layers. It is commonly used to make containers for shipping—such as boxes, cartons, and trays—and seldom used for direct food contact. The various types of paperboard are as follows

White board—Made from several thin layers of bleached chemical pulp, white board is typically used as the inner layer of a carton. White board may be coated with wax or laminated with polyethylene for heat sealability, and it is the only form of paperboard recommended for direct food contact.

Solid board—Possessing strength and durability, solid board has multiple layers of bleached sulfate board. When laminated with polyethylene, it is used to create liquid cartons (known as milk board). Solid board is also used to package fruit juices and soft drinks.

Chipboard—Chipboard is made from recycled paper and often contains blemishes and impurities from the original paper, which makes it unsuitable for direct contact with food, printing, and folding. It is often lined with white board to improve both appearance and strength. The least expensive form of paperboard, chipboard is used to make the outer layers of cartons for foods such as tea and cereals [9].

Fiber board—Fiber board can be solid or corrugated. The solid type has an inner white board layer and outer kraft layer and provides good protection against impact and compression. When laminated with plastics or aluminum, solid fiberboard can improve barrier properties and is used to package dry products such as coffee and milk powder. The corrugated board is made with 2 layers of kraft paper with a central corrugating (or fluting) material. Fiberboard's resistance to impact abrasion and crushing damage makes it widely used for shipping bulk food and case packing of retail food products.

Paper laminates—Paper laminates are coated or uncoated papers based on kraft and sulfite pulp. They can be laminated with plastic or aluminium to improve various properties. For example, paper can be laminated with polyethylene to make it heat sealable and to improve gas and moisture barrier properties. However, lamination substantially increases the cost of paper. Laminated paper is used to package dried

Molded pulp products

Molded pulp products (MPP) can be made from various natural fibrous materials such as wheat straw, sugarcane, and recycled paper. Due to the advantages of low toxicity and biodegradability, MPP have the potential to replace plastic products in a wide range of fields, including food containers and tableware, electronic product packaging, medical and health products, building materials, and living furniture. However, MPP are susceptible to environmental humidity and moisture because of the hygroscopic nature of cellulose fibers. Getting wet may reduce their structural integrity and storage life.

Shopping bags

The ban of disposable plastic bags will increase the growth of paper shopping bags. However, the high cost and inferior mechanical strength of paper shopping bags are the main hurdles to large-scale replacement of plastic shopping bags. Still efforts are needed to develop sustainable additives and Coatings, as well as advanced manufacturing technology to produce high-performance paper for various types of paper shopping bags.

Paper bags – sustainable and efficient packaging of the future

Paper carrier bags are popular among consumers and retailers. Whether for food, fashion, electronics or decorative items – they are strong and reliable shopping companions and have convincing environmental benefits at the same time. Paper fibres are natural and renewable. The cellulose fibres are used as raw material to produce paper bags. They originate from sustainably managed forests wood raw materials. Paper bags store carbon dioxide (CO_2): As young trees grow; they absorb CO_2 from the atmosphere. This offset the fossil CO_2 emissions generated and the carbon stored in the tree's wood fibres remains in all forest products, such as paper bags, and is not released during their life cycle and recycled afterwards. Paper bags have a low climate impact i.e remarkably low impact on the global warming potential compared to low density polyethylene (LDPE) bags. Paper bags show environmental commitment, viz reusable, recyclable and Biodegradable: Using paper bags is an expression of living a sustainable lifestyle and gives a clear signal of having a commitment to the environment.

Barrier Coating in Paper

Plain paper is not used to protect foods for long periods of time because it has poor barrier properties and is not heat sealable. When used as primary packaging (that is, in contact with food), paper is almost always treated, coated, laminated, or impregnated with materials such as waxes, resins, or lacquers to improve functional and protective properties. Paper packaging is an attractive solution for the food and beverage industry for a number of reasons: it's readily available, it's flexible, and it's relatively cost-effective. Unfortunately, untreated cellulosic paper does not prevent the movement of vapor and liquids through its surface. That's because paper has a porous structure, which makes it possible for even small molecules to pass rather easily through the material. At the same time, the hydroxyl groups of cellulosic fibers decrease paper's water resistance. Upon contact with water, paper packaging can begin to deteriorate and lose strength.

To overcome these issues, paper manufacturers and converters coat their paperboard products with materials that improve their barrier performance. Coating blocks the pores of the paper to prevent the transmission of air, water and vapor. These so-called barrier coatings play an important role in ensuring a product's shelf life by protecting food from the decaying influences of chemical, physical and microbiological elements. Packaging must also remain stable, not interacting with the food so that the appearance, smell, taste and texture of the food remain unchanged. Depending on the intended use, coatings may have to meet standards set by the Food and Drug Administration (FDA).

It is possible to make a physical barrier by laminating plastic or aluminium onto paper or paperboard, but this creates some challenges. Better solution is coating with synthetic polymer products, which provide an efficient barrier but are much easier to apply and allow the paper to be repulped and recycled. The performance of a polymer as a barrier coating is affected by a number of factors, including the choice of monomers and the polymerization process.

Desirable Barrier Properties

The challenge with paper-based packaging is that it doesn't have the same barrier properties as plastic (to water, moisture, grease, gas, odour), so it often needs to be treated with a barrier coating to improve performance. A barrier coating is an additional layer applied as a liquid coating onto the substrate to bring extra functionality. The goal is to enable the paper to behave largely in the same way as a plastic package and remain functional in the application. Without a barrier treatment, a paper coffee cup would quickly leak hot coffee; packaged snacks would lose their crunch as moisture penetrates through the packaging. Packages require a high level of barrier, and paper cannot replace plastic in all applications. But, to replace many of the applications where plastic is used with a paper-based alternative, the properties of the paper can be boosted with barrier coatings.

A More Sustainable Barrier Solution

Water-borne polymeric coatings can help overcome that challenge. They can successfully deliver some of the desired barrier properties while still allowing the paper to remain repulpable, leading to reduced plastic usage and increased recyclability. Coating application can be a critical step in achieving the necessary performance. The coating also needs to deliver the functionality required for specific applications beyond barrier properties (i.e., heat sealability, printability, food-contact compliance), and the coated substrate needs to be processable with existing packaging manufacturing equipment. For example, coated cup-stock needs to be sealable at the same speeds and temperatures used with plastic-lined cups so that cup production efficiencies are largely maintained.

The upfront cost of the coating can be more expensive than the plastic it is replacing because polyethylene film is a commodity material, but there are many other considerations to take into account when analysing the total cost: relative overall production costs, the ability to recycle industrial waste, the ability to recycle post-consumer waste, avoidance of packaging taxes and the boost to brand image and the potential resulting increase in sales from this boost for a company that implements sustainable packaging solutions.

Effective Barrier Coatings

Barrier and other functional coating materials that are coated onto substrates to provide a barrier, and a package, to protect selected packaged goods. Barrier coatings, providing barriers for food packaging requirements, may include protection against oxygen and aromas, liquid water and water vapor, oils, and grease. An effective barrier can prevent both losses from the packaged product, and penetration into the package, both of which can affect quality, and shorten product shelf life. Packaged food products are being maintained fresh longer as a result of new materials, and food processing developments. Food packagers have the ability to improve shelf life, preserve product appearance, and flavour, while minimizing preservative use.

Measuring the Performance of Barrier Coatings

The barrier properties of packaging materials most important to the food packaging industry are moisture vapor transmission, liquid water resistance and oil and grease resistance. Chemists use a variety of tests to measure the functional performance of barrier coatings: Moisture vapor transmission is the transfer of water vapor from one side of a package to the other. The water vapor transmission in a specified time range is measured by the moisture vapor transmission rate (MVTR), also known as the water vapor transmission rate. A properly formulated barrier coating for paperboard can achieve an MVTR measurement of < 10 grams/100 in^2/day or < 150 grams/m^2/day.

Liquid water resistance is measured by Cobb test. A product's Cobb value reflects the amount of water that is absorbed from one-sided contact of a defined area of paper with water in a specified time expressed in grams/m^2,. The lower the Cobb value, higher the resistant to water. A properly formulated barrier coating for paperboard can achieve a Cobb value of <1 grams/m^2.

Oil and grease resistance in a barrier coating was traditionally measured by Kit test. This test involves applying varying mixtures of castor oil, toluene, heptane and turpentine to a product for 15 seconds. Each mixture is scored a number on a scale of 0 to 12, from least aggressive to most aggressive. The highest numbered mixture that does not stain the surface is reported as the "kit rating." Hot oils and greases are also used for testing, which better reflect how well a synthetic polymer-based barrier coating resists actual greases that food packaging typically contacts.

Customized Barrier Coating Solutions for the Food Packaging Industry

Barrier coatings are produced with styrene-butadiene, styrene-acrylic, and all-acrylic water-based emulsion polymers. The polymers are applied to paper, paperboard, and cardboard in thin layers that are sometimes imperceptible to the consumer. A variety of methods can be used to apply barrier coatings for food packaging, including conventional paper machine coaters and off-machine coaters and flexographic printing presses. Choosing the appropriate application process is important to optimize product performance.

SELECTION OF PLOYMERS FOR BARIER COATINGS

Early barrier coatings for food packaging were made from synthetic polymeric chemicals known as per- and polyfluoroalkyl substances (PFAS). PFAS are a diverse class of compounds characterized by having a hydrophobic (water-hating), fluorine-saturated carbon chain joined to a hydrophilic (water-loving) functional group. This unique structure gives PFAS the ability to repel both water and fat readily. Unfortunately, PFAS can't be separated from the paper easily, which means the paper can't be recycled or repulped. The whole family of compounds has also been shown to have harmful effects on human health. Another class of synthetic polymers, known as emulsion polymers, can also be used as barrier coatings. Like PFAS, emulsion polymers can help extend the shelf life of foods by providing a barrier to moisture vapor and oxygen, and they can provide oil, grease and water resistance.

Coating with Edible oil

Edible additives are one of the promising alternatives used for cellulosic paper, especially for food packaging applications. The edible additives can be biobased polymers such as starch, carboxymethylcellulose, protein, chitosan, and rosin, as well as mineral particles (e.g. bentonite, calcium carbonate, and silica). These edible additives are expected to be used for both internal and surface applications, which may provide enhanced mechanical strength, water resistance, and barrier properties of the final products [11].

Coating with Polylactic acid;

Recently, biopolymers have considerable interest as a replacement for petrolic synthetic polymers. Poly (lactic acid) (PLA) is a non-toxic, compostable bio-based material derived from starch and sugar. It is accepted as GRAS (Generally Recognized as Safe) by the Food and Drug Administration (FDA) and is suitable for using in food and beverage packaging. PLA has perfect attributes such as high mechanical strength, high modulus, biodegradability, biocompatibility, bio absorbability, transparency, energy savings, low toxicity and easy process ability [12.13]. Moreover, PLA has a wide range of applications such as in agricultural films, biomedical devices, packaging, and automotive industries due to its great properties [14]. Furthermore, PLA has given significant attention in food packaging applications with films or coatings. Commercial PLA is amorphous in nature and has good optical transparency, making it suitable for packaging applications.

But the main drawback is its poor resistance properties of oxygen permeability (OP) of ~ 540 cc (gm) mil/m 2 - day atm and water vapor permeability (WVP) of 1.96 g mm m 2 day [18]. Now some of the products are available in the market with this coating in Food application.

Polyglycolic acid:

Polyglycolic acid (PGA) got special attention nowadays because it gives excellent barrier properties, and the production of glycolic is through the natural route [15]. The structure of PGA is similar to the PLA, but PGA exhibits higher gas barrier properties with excellent mechanical strength, making it more attractive for packaging applications. The moisture and oxygen permeability of the PGA is 0.2 g mm/ m 2 day and 0.014 cc mm/ m 2-day atm, respectively [16].

Poly hydroxy alkenoates

Biodegradability, inherent hydrophobicity, non-permeability, insolubility, and flexibility made poly hydroxy alkenoates (PHA) as a potential competitor for petroleum-based polymers in the packaging [17]. PHA family consists of polyhydroxy butyrates (PHB), polyhydroxy butyl vinyl (PHBV), and polyhydroxy butyl hydroxyl (PHBH), etc., [18]. PHA is mainly used in the packaging sector as paper coatings, carpets, shopping bags, paper cups and diapers, etc. Nowadays, many PHA-coated products are available in the market in the form of boxes, boards, papers, etc.. PHB, PHBV, and PHBH provide good oxygen and water vapor permeation barrier of<50 cc (gm) mil/m^2 -day-atm. The crystalline nature of nearly 60% of the PHBV with low hydroxy valerate content contributes to the high barrier properties of the PHBV. But drawbacks such as physical aging at room temperature, inherent brittleness, and narrow processing window limit their full-scale application.

Polybutylene succinate (PBS)

Polybutylene succinate (PBS) is a bio-based and degradable aliphatic polyester that can be used in food packaging applications at elevated temperatures. PBS degrades at high rates of 13 mg/cm 2 weight loss per month, making it an attractive material for food packaging applications [19]. The production cost of PBS is high compared to petroleum-based polymers such as polyethylene (PE), polystyrene (PS), polyethylene terephthalate (PET), and polyamides (PAs) [20]. PBS has oxygen/water vapor permeability values in the range similar to polylactic acid (PLA), and oxygen barrier properties are in the range of ~ 200 ~ 300 cc mil/m 2 -day- atm for semi-crystallized PBS with ~ 35% of crystallinity [20]. Polybutylene succinate (PBS) is the biodegradable plastic that decomposes into water and carbon dioxide with the microorganism under the soil. PBS has a high heat resistance among the general biodegradability resin, and PBS has high compatibility with a fiber.

Challenges with biodegradable polymer as a coating material

Petroleum-based polymers show better mechanical and barrier properties with lower costs compared to natural biodegradable polymers [21]. Even though natural biopolymers have biocompatibility, they possess undesirable properties like antigenicity and inconsistency in the different batches of production [22]. There are more chances for microbial contamination in the case of natural biopolymers during production and handling. Polysaccharides such as starch, cellulose, hemicellulose, zein, gum arabic, pectin, and chitosan are hydrophilic in nature and cannot provide good barrier properties when they are coated alone.

To get good barrier properties, these biopolymers need to blend with other materials like polyvinyl alcohol (PVOH) [23]. The problems with biopolymers are high molecular weights, hydrophilicity, brittleness, high viscosity, and uncertainties in melting. The main challenge for paper packaging is the low mechanical properties of paper which are increasing the usage of synthetic polymers at the industrial level. Moreover, the other major concern is deforestation causing due to the raw material procurement for biopolymers preparation. Many starch-based nanocomposites are developed to increase the performance of coatings with more added functionalities to the coatings based on starch. But the large-scale utilization of starch-based coatings has not yet been realized. Further, it is essential to evaluate the toxicity of the nanocomposites based on starch as they might transfer into the food material when used for food packaging. Biopolymer coating on paper for packaging applications is still at its initial stage of development.

Conclusion

In the context of plastic ban, paper products can replace many plastic products and have numerous advantages in terms of sustainable development and environmental protection. This makes them promising green packaging materials. This is the better opportunity for the pulp and paper manufacturers. Most of the integrated paper mills are making only base paper for food grade application. SPB makes various multilayer base paper for food grade application like cup making and Plate making etc. These products are mainly from virgin pulp and all of them are adhering the FDA Norms i.e free from heavy metals and toxic elements – Tested and certified by TUV (Independent Inspection Agency) for food grade application. Converters are making several products in these areas.

Poor mechanical properties, barrier properties, and high processing costs compared to conventional petroleum-based polymers are retarding commercialization on an industrial scale. Blending different biopolymers like polylactic acid and polycaprolactone can give desired barrier properties, and we can overcome the drawbacks of individual biopolymers. The industrialization of biopolymer coatings on paper-based packaging requires further research, which can improve the product's packaging at a reduced production cost.

Thus, papermakers need to devote effort to develop advanced manufacturing technologies for the low-cost production of high-performance products. Focus on barrier coating with suitable blends of polymeric materials and technological upgradation is essential to match the required properties. If CFTRI can develop clear-cut formulations for Barrier coatings, testing methods with tolerance norm as per FDA regulations, which will be more useful for manufacturers and consumers.

Acknowledgement

The authors gratefully acknowledge the Seshasayee paper and boards ltd management for giving support and permission to publish this article.

References

1. www.statista.com – Global Plastic production
2. (Division of Agricultural Sciences and Natural Resources • Oklahoma State University) (August 2021)
3. Pro Carton, Cartons' Modern Design & Production, 2017
4. Han, J. H. 2000. Antimicrobial food packaging.Food Technol. 54(3):56-65.
5. Liu et al. (2020). "Paper as substitute for plastic," Bio Resources 15(4), 7309-7312
6. Source: https://en.wikipedia.org/wiki/Polyethylene_terephthalate
7. Kirwan, M. J. 2011. Paper and Paperboard Packaging in Food and Beverage Packaging Technology, R. Coles and M. Kirwan (Eds.), 2nd Ed., Wiley-Blackwell, Oxford, UK.

8. Application of plastics and paper as food packaging materials – An overview Dele Raheem, Department of Food and Environmental Sciences, P.O. Box 56 University of Helsinki, Finland

9. Marsh, K. and B. Bugusu. 2007. Food packaging – roles, materials and environmental issues. J. Food Sci. 72(3):39-55.

10. Kumar, S., A. Mukherjee, and J. Dutta. 2020. Chitosan based nanocom- posite films and coatings: emerging antimicrobial food packaging alternatives. Trends in Food Science & Technology 97:196–209. doi: 10.1016/j. tifs.2020.01.002.

11. Hagen R (2012) Polylactic Acid. Polym Sci : a comprehensive ref- erence 10:231–236. https://doi.org/10.1016/ B978-0-444-53349-4. 00269-7

12. Deshwal GK, Panjagari NR, Alam T (2019) An overview of paper and paper based food packaging materials: health safety and environmental concerns. J Food Sci Technol 10:4331-4403 Springer. https://doi.org/ 10.1007/ s13197-019-03950-z

13. Taib NAAB et al. (2022) A review on poly lactic acid (PLA) as a biodegradable polymer. Polym Bull 1–35

14. Sundar N, Ananda Kumar S, Pavithra A, Ghosh S (2020) Studies on semi- crystalline poly lactic acid (PLA) as a hydrophobic coating mate- rial on kraft paper for imparting barrier properties in coated abrasive applications. Progress in Organic Coatings 145:105682

15. Samantaray PK et al. (2020) Poly(glycolic acid) (PGA): A versatile building block expanding high performance and sustainable bio- plastic applications. Green Chemistry. Royal Society of Chemistry

16. Polyglycolic acid - 22(13):4055-4081. https://doi.org/10.1039/d0gc01394c

17. Israni N, Shivakumar S (2019) Polyhydroxyalkanoates in packaging. in Biotechnological Applications of Polyhydroxyalkanoates, Springer Singapore, pp. 363–388. https://doi. org/10.1007/978-981-13-3759-8_ 14

18. Tyagi P, Salem KS, Hubbe MA, Pal L (2021) Advances in barrier coatings and film technologies for achieving sustainable packaging of food products – a review. Trends Food Sci Technol 115:461–485.

19. Deshmukh RK, Akhila K, Ramakanth D, Gaikwad KK (2022) Guar gum/ carboxymethyl cellulose based antioxidant film incorporated with halloysite nanotubes and litchi shell waste extract for active packaging. Int J Biol Macromol 201:1–13. https://doi. org/ 10.1016/J.IJBIOMAC.2021.12.198

20. Doppalapudi S, Jain A, Khan W, Domb AJ (2014) Biodegradable polymers— an overview. Polym Adv Technol 25(5):427–435. https://doi. org/10.1002/PAT.3305.

21. S. Bhatia (2016) Natural polymer drug delivery systems: Nano- particles, plants, and algae. Natural Polymer Drug Delivery Sys- tems: Nanoparticles, Plants, and Algae pp 1–225

22. Thurber H, Curtzwiler GW (2020) Suitability of poly(butylene suc- cinate) as a coating for paperboard convenience food packaging. Int J Biobased Plast 2(1): 1–12. https://doi. org/10.1080/24759651.2020. 1785094

23. Rafiqah SA et al (2021) A review on properties and application of bio- based poly (Butylene succinate). Polymers (Basel) 13(9):1–28.