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FOCUS ON PRINCIPAL PROPERTIES OF BIOBASED PACKAGING MATERIALS FOR THE FOOD INDUSTRY

Serkan Ötles[1], Semih Ötles[2]
[1]Izmir Institute of Technology, Turkey
[2]Ege University of Izmir, Turkey

Abstract. At the turn of the last century most non-fuel industrial products; dyes, inks, paint, medicines, chemicals, clothing, synthetic fibres and plastics were made from biobased resources. By the 1970s petroleum-derived materials, had to a large extent, replaced those materials derived from natural resources. Recent developments are raising the prospects that naturally derived resources again will be a major contributor to the production of industrial products. Currently, scientists and engineers successfully perform developments and technologies that will bring down costs and optimise performance of biobased products. At the same time environmental concerns are intensifying the interest in agricultural and forestry resources as alternative feedstocks. A sustained growth of this industry will depend on the development of new markets and costs and performance competitive biobased products. A potential new market for these materials is food packaging, a highly competitive area with great demands for performance and cost.

Key words: biobased, food processing, polymers, food quality

INTRODUCTION

Designing and manufacturing of packaging materials is a multi-step process and involves careful and numerous considerations to successfully engineer the final package with all the required properties.

The properties to be considered in relation to food distribution are manifold and may include gas and water vapour permeability, mechanical properties, sealing capability, thermoforming properties, resistance (towards water, grease, acid, UV light, etc.), machinability (on the packaging line), transparency, anti fogging capacity, printability, availability and, of course, costs.

The aim of this report is to evaluate the potential of biobased packaging materials for the food industry, and the most important properties in relation to food applications can be narrowed down to four intrinsic properties of the material: mechanical, thermal,

Corresponding author – Adres do korespondencji: Serkan Ötles, Chemical Engineering Department of Izmir Institute of Technology, Izmir, Turkey, e-mail: otles@bornova.ege.edu.tr

gas barrier and water vapour properties, and the focus will be on these four properties. Compostability, which is a very appealing property when the packaging meets its end of useful life, will also be described. The most common biobased polymers and potential biobased packaging materials are presented, followed by a discussion of their food packaging properties [Coombs and Hall 2000].

GAS BARRIER PROPERTIES

Many foods require specific atmospheric conditions to sustain their freshness and overall quality during storage. Hence, increasing amounts of our foods are being packed in protective atmosphere with a specific mixture of gases ensuring optimum quality and safety of the food product in question. To ensure a constant gas composition inside the package, the packaging material needs to have certain gas barriers. In most packaging applications the gas mixture inside the package consists of carbon dioxide, oxygen and nitrogen or combinations hereof. The objective of this section is to describe the gas barriers of biobased materials using mineral oil based polymer materials as benchmarks.

Literature provides a vast amount of information on the barrier properties of biobased materials. However, comparisons between different biobased materials are complicated and sometimes not possible due to the use of different types of equipment and dissimilar conditions for the measurements.

In Figure 1, different biobased materials are compared to conventional mineral-oil-based polymer materials. The figure is based on information from literature and on measurements of commercially available materials performed by ATO.

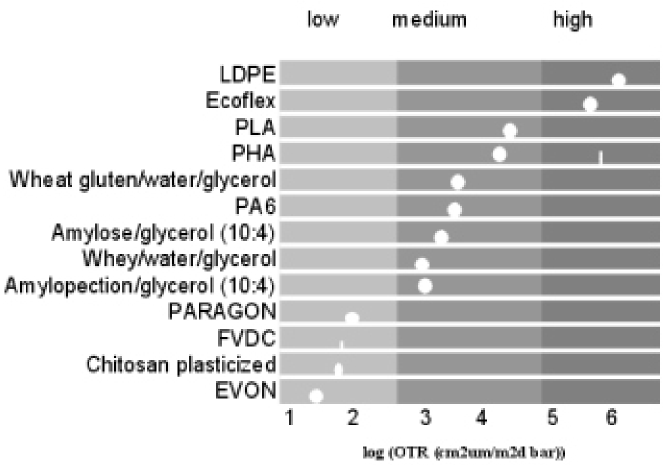

Fig. 1 Comparison of oxygen permeability of biobased materials compared to conventional mineral-oil-based materials [Rindlav--Westling et al. 1998]

Rys. 1. Przepuszczalność tlenu przez wybrane polimery w porównaniu z przepuszczalnością polimerów syntetycznych [Rindlav-Westling i in. 1998]

As seen in Figure 1, biobased materials mimic quite well the oxygen permeabilities of a wide range of the conventional mineral-oil-based materials and it is possible to choose from a range of barriers among the presented biobased materials. It is noteworthy that developments are still being made.

The conventional approach to produce high-barrier films for packaging of food in protective atmosphere is to use multi-layers of different films to obtain the required properties. A laminate that is often used in food packaging consists of layer of EVOH or PA6 combined with LDPE combining the gas barrier properties of PA6 or EVOH with the water vapour barrier, the mechanical strength and the excellent sealing properties of the LDPE. A similar multi-layer approach for biobased materials may likewise be used to produce materials with the required properties. As seen in Figure 1 starch-based materials could provide cheap alternatives to presently available gas barrier materials like EVOH and PA6 and an equivalent biobased laminate would be an outer layer of plasticized chitosan, a protein or starch-derived film combined with PLA or PHA. Notably, the gas barrier properties of PA6 and EVOH are sensitive towards moisture and the LDPE creates a very effective water vapour barrier ensuring that the moisture from the foodstuff does not interfere with the properties of PA6 or EVOH. In the same fashion, PLA and PHA will protect the moisture-sensitive-gas-barrier made of polysaccharide and protein. Some interesting developments have made it possible to improve water vapour and gas properties of biobased materials many-fold by using plasma deposition of glass-like SiOx coatings on biobased materials or the production of nano-composites out of a natural polymer and modified clay [Fischer et al. 2000, Johansson 2000].

In general, the oxygen permeability and the permeability of other gases of a specific material are closely interrelated and, as a rule of the thumb, mineral oil based polymers have a fixed ratio between the oxygen and carbon dioxide permeabilities. This relation is also observed for biobased materials. However, for some biobased materials, e.g. PLA and starch, the permeability of carbon dioxide compared to oxygen is much higher than for conventional plastics [Petersen and Nielsen 2000].

GAS BARRIERS AND HUMIDITY

As many of these biobased materials are hydrophilic, their gas barrier properties are very much dependent on the humidity conditions for the measurements and the gas permeability of hydrophilic biobased materials may increase manifold when humidity increases. Notably, this is a phenomenon also seen with conventional polymers. The gas permeability of high gas barrier materials, such as nylon and ethylvinyl alcohol, is likewise affected by increasing humidity. Gas barriers based on PLA and PHA is not expected to be dependent on humidity.

WATER VAPOUR TRANSMITTANCE

A major challenge for the material manufacturer is the by nature hydrophilic behaviour of many biobased polymers as a lot of food applications demand materials that are resistant to moist conditions. However, when comparing the water vapour transmittance of various biobased materials to materials based on mineral oil (see Fig. 2), it becomes clear that it is possible to produce biobased materials with water vapour transmittance rates comparable to the ones provided by some conventional plastics. However, if a high water vapour barrier material is required, very few biobased materials apply. Notably, developments are currently focusing on this problem and future biobased materials must also be able to mimic the water vapour barriers of the conventional materials known today.

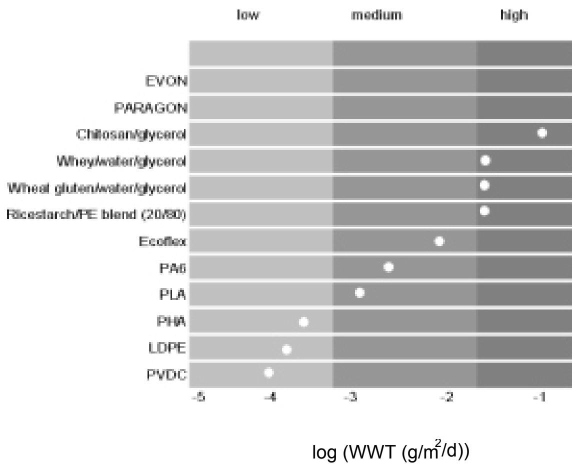

Fig. 2. Water vapour transmittance of biobased materials compared to conventional packaging materials based on mineral oil [Rindlav-Westling et al. 1998]
Rys. 2. Przepuszczalność pary wodnej przez wybrane biopolimery w porównaniu z przepuszczalnością polimerów syntetycznych [Rindlav-Westling i in. 1998]

THERMAL AND MECHANICAL PROPERTIES

Next to the barrier properties of the final packaging, the thermal and mechanical properties of the materials are both important for processing and also during the use of the products derived from these materials. Most biobased polymer materials perform in a similar fashion to conventional polymers. This indicates that both polystyrene-like polymers (relatively stiff materials with intermediate service temperatures), polyethylene-like polymers (relatively flexible polymers with intermediate service temperatures) and PET-like materials (relatively stiff materials with higher service temperatures) can be found among the available biobased polymers. The mechanical properties in terms of modulus and stiffness are not very different compared to conventional polymers. In Figure 3 a comparison of the thermal properties of biobased polymers with existing polymers is made. The modulus of biobased materials ranges from 2500-3000 MPa and lower for stiff polymers like thermoplastic starches to 50 MPa and lower for rubbery materials like medium chain polyhydroxyalkanoates.

Furthermore, the modulus of most biobased and petroleum derived polymers can be tailored to meet the required mechanical properties by means of plasticizing, blending with other polymers or fillers, crosslinking or by the addition of fibres. A polymer like bacterial cellulose could for instance be used in materials which requires special mechanical properties. In theory, biobased materials can be made having similar strength to the ones we used today [Iguchi et al. 2000].

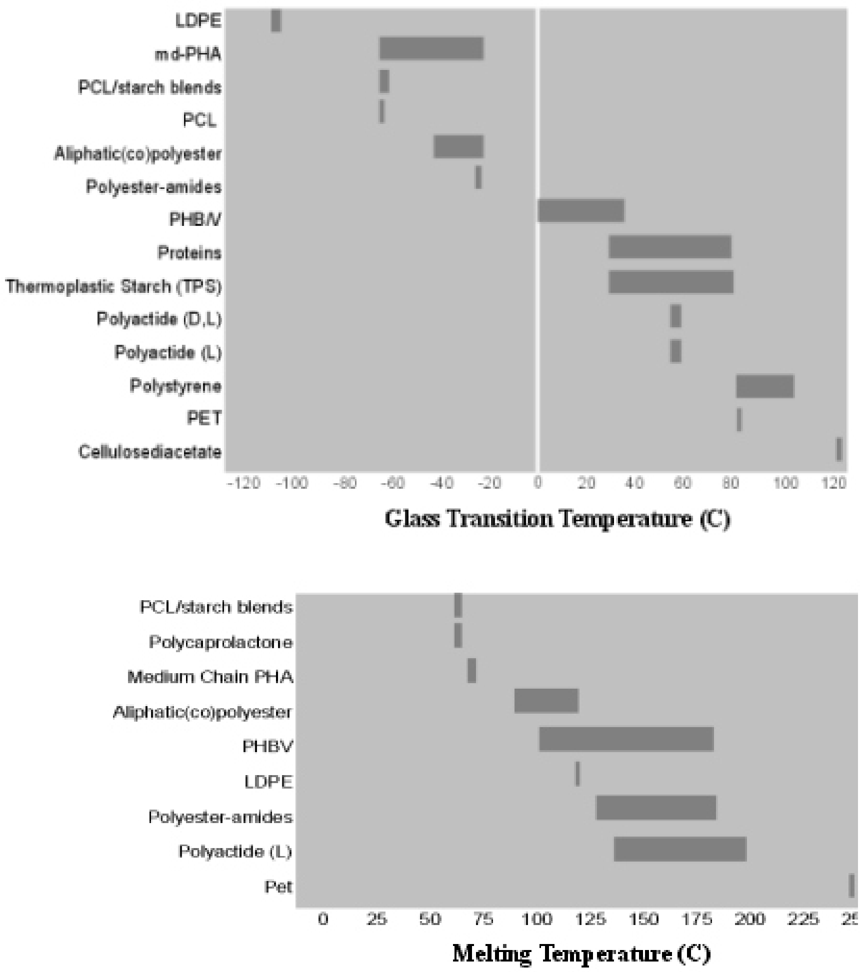

Fig. 3 Comparison of the thermal properties of biobased polymers with conventional polymers [Iguchi et al. 2000]
Rys. 3. Porównanie termicznych właściwości biopolimerów i polimerów syntetycznych [Iguchi i in. 2000]

COMPOSTABILITY

Figure 4 compares the compostability of various biobased materials. Notably, the "composting time" depicted in the Figure represents the approximate period of time required for an acceptable level of disintegration of the material to occur. This means that the original material should not be recognisable anymore in the final compost (fraction < 10 mm) nor in the overflow (fraction > 10 mm). The composting time does not reflect the time required for the biodegradation of the materials to be fully completed. The process could subsequently be completed during the use of the compost. The level of technology applied in the composting process highly affects the composting time needed for complete disintegration. Hence, it takes much longer to obtain a mature compost using low technology composting (e.g. passive windrow composting) than using high technology as in an intensively controlled tunnel composting process [Iguchi et al. 2000].

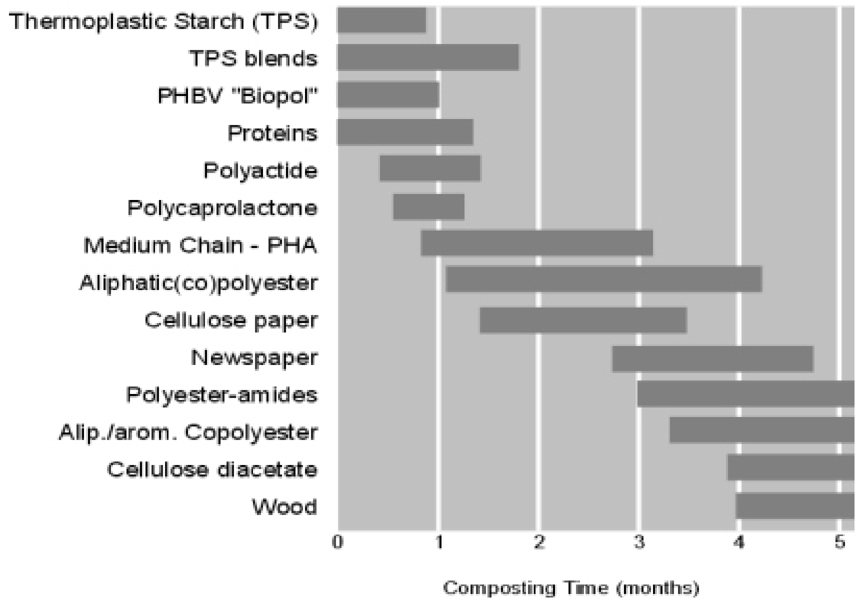

Fig. 4. Indication of the time required for composting of various biobased and synthetic polymeric materials [Johansson 2000]
Rys. 4. Czas niezbedny do rozkładu wybranych biopolimerów i polimerów syntetycznych [Johansson 2000]

The durations presented in Figure 4 are based on an intermediate level of technology as observed in actively aerated and mechanically turned hall composting. Furthermore, the composting time needed for complete disintegration is also affected by the particle size of the material. For example, wood is rapidly composted in the form of sawdust and small chips. A wooden log, however, takes more than one year to be completely disintegrated. The durations presented in this Figure are based on dimensions regularly used for packaging applications. The compostability of the materials are highly dependent on the other properties of the materials, e.g. the first step of the composting is often a hydrolysis or wetting of the material. The rate of this step is very much related to the water vapour transmittance and the water resistance of the material. Hence, the composting rate of a material will be dependent on its other properties [Iguchi et al. 2000, Butler et al. 1996].

CONCLUSION

Today, biobased polymers have an increasing importance. The main reason is the fact that they are produced from renewable resources and also they can be recycled. Biobased polymers have different categories according to different production methods and different applications in food industry.

The materials used for food packaging today consist of a variety of petroleum derived plastic polymers, metals, glass, paper and board, or combinations thereof. These materials and polymers are used in various combinations to prepare materials with unique properties which efficiently ensure safety and quality of food products from processing and manufacturing through handling and storage and, finally, to consumer use.

Notably, these materials fulfil a very important task as absence of packaging or insufficient packaging would result in fast deterioration of quality and safety giving way to massive commercial losses of valuable foodstuffs. Individual food products have specific optimum requirements for storage that the packaging materials must be able to provide. When contemplating the concept of food packaging, the entire dynamic interaction between food, packaging material and ambient atmosphere has to be considered. Hence, engineering of new biobased food packaging materials is a tremendous challenge both to academia and industry.

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PODSTAWOWE WŁAŚCIWOŚCI MATERIAŁÓW SŁUŻĄCYCH DO PRODUKCJI BIOOPAKOWAŃ NA POTRZEBY PRZEMYSŁU SPOŻYWCZEGO

Streszczenie. W ostatnim czasie coraz więcej wyrobów przemysłowych jest produkowanych z naturalnych i odnawialnych surowców. Coraz więcej ośrodków naukowych pracuje nad technologiami pozwalającymi na szersze wykorzystanie tych surowców przy obniżeniu kosztów ich przerobu. Dalszy rozwój tych technologii będzie możliwy po ich upowszechnieniu i zwiększeniu opłacalności ich wykorzystania. Nowym, potencjalnie dużym kierunkiem wykorzystania tych surowców wydaje się produkcja bioopakowań na potrzeby przemysłu spożywczego.

Słowa kluczowe: bioopakowania, produkcja żywności, polimery, jakość żywności

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