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PRODUCTION AND APPLICATIONS OF BIO-BASED PACKAGING MATERIALS FOR THE FOOD INDUSTRY

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Materials based on renewable resources are being developed at an increasing rate. Today, the only bio-based food-packaging materials used commercially on a major scale are based on cellulose. However, materials based on proteins, starch, polylactate and other renewable resources may be the food-packaging materials of tomorrow. The paper presents some of the different bio-based materials and their potential as food packaging materials.

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, thermo-forming properties, resistance (towards water, grease, acid, UV light, etc.), machinability (on the packaging line), transparency, anti fogging capacity, printability, availability and, of course, costs. Moreover, a consideration of the "cradle to grave" cycle of the packaging material is also required, hence, the process of disposal of the package at the end of its useful life must also be taken into consideration. The aim of this report is to evaluate the potential of bio-based packaging materials for the food industry.

Considerations for Use of Different Packaging Materials

The key to successful packaging is to select the package material and design that best satisfy competing needs with regard to product characteristics, marketing considerations (including distribution needs and consumer needs), environmental and waste management issues, and cost. Not only is balancing so many factors difficult, but also it requires a different analysis for each product, considering factors such as the properties of the packaging material, the type of food to be packaged, possible food/package interactions, the intended market for the product, desired product shelf-life, environmental conditions during storage and distribution, product end use, eventual package disposal, and costs related to the package throughout the production and distribution process. Some of these factors are interrelated: for example, the type of food and the properties of the packaging material determine the nature of food package interactions during storage. Other times, the factors are at odds with each other: for example, single-serving packaging meets consumer needs, but bulk packaging is better for environmental reasons.

A thorough knowledge of product characteristics, including deterioration mechanisms, distribution needs, and potential interactions with the package, is essential for package design and development. These characteristics concern the physical, chemical, bio-chemical, and microbiological nature of the product. Materials that provide optimum protection of product quality and safety are most preferred. Similarly, distribution systems and conditions help determine the type of packaging material used.

Bio-based Packaging Materials

Cellulose

The future generation of packaging materials will be derived from renewable resources. These materials will ideally be biodegradable. Cellulose is a good example. It is the most abundant natural polymer on earth and it is an essentially linear polymer of anhydroglucose. It is a cheap raw material costing between 0.5 and 1 ECU per kg before derivatization. As a consequence of its chemical structure, it is highly crystalline, fibrous, and insoluble . Hence, for film production, cellulose is dissolved in an aggressive, toxic mixture of sodium hydroxide and carbon disulphide ("Xanthation"') and then recast into sulphuric acid. This produces a cellophane film. Cellophane has good mechanical properties. It is hydrophilic and, consequently, sensitive to moisture. Cellophane is not thermoplastic and is, therefore, not heat-sealable. It is often coated, e.g. with nitrocellulose wax (NC-W) or poly-vinylidene chloride (PVDC), because of its relatively poor moisture barrier properties. At low relative humidity levels cellophane is a good gas barrier; however, barrier properties are reduced at intermediate and high relative humidities. Coating reduces the influence of the relative humidity on the barrier properties , but inevitably increases production cost. Alternatively, cellulose may be derivatized from the solvated state, via esterification or etherification of individual hydroxyl groups on the polysaccharide backbone. A number of derivatives are commercially available, including cellulose acetate, ethyl cellulose, hydroxy-ethyl cellulose, and hydroxy-propyl cellulose.

Cellulose modification is, therefore, costly and difficult; the least expensive derivative is the diacetate costing around 3±4 ECU per kg [50]. For realistic thermoplastic processing, cellulose acetate needs addition of up to 25% plasticizer. There may be considerable potential for the use of a bio-derived plasticizer. However, at present, none is commercially utilized. The gas and moisture barrier properties of cellulose acetate are not optimal with respect to food packaging. Some grades of cellulose acetate (degree of substitution less than 1.7) are biodegradable, although at a slower rate than cellophane.

Starch

Starch is another widely abundant polysaccharide obtained in granular form from corn, cereal grain, rice, and potatoes. Starch is essentially a mixture of amylose, an almost linear polymer of anhydroglucose, and amylopectin, a highly branched polymer of anhydroglucose. The ratio of the two components varies according to starch types utilized. Starch enjoys wide usage in several non-food sectors, most notably in the sizing and coating of papers, as an adhesive, a thickener, and as a ``green strength'' additive to simple composite materials such as briquettes. In the packaging field, starch recently has received great attention. It is very biodegradable and has inherently low cost (0.5 ± 1.5 ECU per kg), but is also very hydrophilic (poor moisture barrier). Finally, it is partially crystalline.

Films based on starch have moderate gas barrier properties. Their mechanical properties are generally inferior to synthetic polymer films. When a plasticizer, such as water, is added starches exhibit thermoplastic behavior. Because of these factors, starch requires substantial processing before a stable film is produced. This is generally achieved via ``destructuration'' and plasticization in an extruder, or modification. It is also common practice to add copious amounts of synthetic polymer to the starch. This is normally polyvinyl alcohol (PVA) or olycaprolactone. Films produced have reasonable transparency. The starch component of the Film is truly biodegradable; the other components degrade during composting. This is significantly dfferent to the older technology in which starch was blended with PE to produce a Film which disintegrates, the starch component biodegrades, leaving small particles of PE. Starch PVA materials are, however, very sensitive to moisture. Furthermore, hydrophobation increases costs . An alternative strategy is direct chemical modocation of the starch. Industry produces modified starch for a number of end uses already, but this normally represents only surface modification of starch granules (e.g. cationic starches for paper treatment) . Few ``fully" modified starches are on the market at present. The modification route is likely to be costly, although starch is less crystalline and more chemically accessible than cellulose. In addition, starch is more vulnerable to degradation during modification than cellulose, and conditions employed need to be mild to prevent extensive depolymerization and loss of properties. Research is needed in this area to utilize the full potential of starches. Despite all of the above factors, starch remains the most promising of the available polysaccharides for food packaging, as it is easier to process than cellulose, is low cost, and very biodegradable. The challenge lying ahead is to develop strategies to improve the moisture stability of starch films without eliminating these favourable factors.

Proteins

Proteins have commanded renewed attention as degradable, renewable polymer films. Traditionally, proteins are used in adhesives and as edible films/coatings. However, they have considerable potential as slowly degrading packaging films. Proteins are attractive to the polymer chemist as they possess a wide range of chemical functionalities, and molecules with wide ranges of properties are available in nature. Extrusion applications are possible with respect to plant proteins such as wheat glutens and seed proteins. Animal proteins, such as casein, keratin and collagen, are also available. However, proteins derived from ``waste animal tissue" like collagen are unlikely to be attractive from the consumer standpoint because of recent adversepublicity deriving from the BSE crisis in the British Isles. Protein films have demonstrated good gas barrier properties and many are water resistant, though not entirely hydrophobic . A barrier to the mass processing of plant proteins as packaging film is a lack of basic knowledge as to the tertiary and quaternary structures of complex materials such as gluten. These data are needed for full utilization of the materials in packaging. Potential costs of protein films range from 1±10 ECU per kg. By way of contrast, the Biopol 2 type products [poly-hydroxyalkanoates (PHA)] possess excellent film-forming and coating properties. PHAs are produced with properties close to PE, polypropylene (PP) or polyester (PET). They are biodegradable on soil contact, water resistant, and are readily processed in standard industrial plastic plants. The present barrier to bulk use is cost. This is partially connected with the manufacturing route (for example, isolation of the polymer from the microorganisms is generally costly), and partly produc-tion scale. The properties of the film may be adjusted by changing the ratio between hydroxyvalerate (HV) and hydroxybutyrate (HB), which can be achieved by manipulation of the growth media. A high content of polyhydroxybutyrate (PHB) gives a strong and sti material, whereas polyhydroxyvalerate (PHV) improves flexibility and toughness. The polyalkanoates are more hydrophobic than the polysaccharide-based materials resulting in a material with good moisture barrier properties, whereas the gas barriers are inferior. The polymer currently costs around 10±12 ECU per kg, as compared with an originally projected kg cost of 3±5 ECU [58]. If this projected cost is realised, the potential of this polymer type in packaging is excellent. Figure 3 illustrates the structure of PHA.

Polylactates (PLAs)

Polylactates (PLAs) A more immediate option is polylactates (PLAs) produced via classical polymerization of the renewable fermentation product, lactic acid. Polylactates also perform well compared with standard thermoplastics, and the production of Øexible, water-resistant film has been demonstrated. Again, the material is very bio- degradable under controlled conditions and can be processed using standard industrial machinery. Although not yet produced in bulk, larger scale production is being evaluated by at least two companies (Cargill Dow Polymers and Neste). Prices of around 2±4 ECU per kg are forecast, and if prices of approximately 2 ECU per kg are achieved the packaging potential is very high, assuming adequate barrier properties can be met. Poly-lactates have good mechanical properties. The moisture barrier is better than for the starch-based materials, whereas the gas barrier is inferior. The final polymer cost may well depend on the efficiency of the initial fermentation process to produce the lactic acid monomer as the polymerization step is an adaptation of industry practice for production of stepwise polymers.

The bio packaging material may contain further natural extracts/components, e.g. lignin and waxes which act as preservatives stalling the initial spoilage process of the food product. This process still needs thorough testing. Furthermore, the use of natural antioxidants, plasticizers, etc. in the production of bio-based packaging materials should be addressed. In general, bulk commodity thermoplastics commonly used in food and drink packaging such as PE, PS, and PET are made in high volume at large production plants, and as such are relatively inexpensive due to economy of scale and relatively low unit processing costs. PE costs around 0.7±1 ECU per kg, whereas PS costs twice as much. Because of this quantity, continuous production, product quality and performance is now easy to monitor, and parameters such as moisture and gas barrier of films are reproduced readily. Many of the natural polymer derivatives (cellulose esters and ethers, starch derivatives, etc.) are still produced in batch reactors and are hence more expensive and subject to quality variations. Despite the relatively low cost of the starting materials. A key factor in the spreading of bio-derived polymers in food packaging is, therefore, the development of analogous continuous processes for manufacture of biopolymer film at reduced cost and to a pre-defined quality. Another key factor in this is production of polymer resins that can readily be processed into film using existing industrial machinery, only necessitating minor modification of the production plant. In this respect, the polymers with the best prospects for commercial production are the polylactates and the PHA's, provided initial fermentation or bio-production costs can be reduced. In addition, the starch based systems which can be continuously extruded are promising, provided factors such as moisture resistance and moisture barrier can be improved.

Biopackaging of Foods

One of the challenges facing the food packaging industry in its efforts to produce bio-based primary packaging is to match the durability of the packaging with product shelf-life. The biologically based packaging material must remain stable without changes of mechanical and/or barrier properties and must function properly during storage until disposal. Subsequently, the material should biodegrade efficiently. Environmental conditions conducive to biodegration must be avoided during storage of the food product, whereas optimized conditions for biodegration must exist after discarding. The most important parameters for controlling stability of the biologically based packaging material are appropriate water activity, pH, nutrients, oxygen, storage time, and temperature. Thus, dry products may be safely stored for extended periods, whereas moist foods would have limited storage periods . Prior to using bio-based materials for primary food packaging, the effects on food quality and food safety must be examined.

For many years, coated cellophane and cellulose acetate have been utilized for food packaging. Coated cellophane is used for e.g. baked goods, fresh produce, processed meat, cheese, and candy. Cellulose acetate is used mainly for baked goods and fresh produce . The moisture and gas barrier properties of cellulose acetate are not optimal for food packaging. However, the film is excellent for high-moisture products as it allows respiration and reduces fogging .Recently, a biodegradable laminate of chitosan-cellulose and polycaprolactone film was developed in Japan.

Makino and Hirata (1997) examined the applicability of the laminate for modified atmosphere packaging (MAP) of horticultural commodities. The suitability of the laminate for MAP of head lettuce, cut broccoli, whole broccoli, tomatoes, and sweet corn was tested by computer simulation using respiration rate equations stated in the literature. The results encourage use of the biodegradable laminate for the above mentioned products within a 10±25C temperature range.

Scientific tests have been performed on starch containing materials for use in food packaging . Holtonet al . (1994) evaluated the suitability of an ordinary polyethylene (PE) film and a PE film containing 6% corn starch when used for packaging of broccoli, bread, and ground beef stored under normal time and temperature conditions. The type of packaging film seemingly did not affect the evaluated quality parameters, i.e. bread staling, broccoli colour, and lipid oxidation of ground beef. However, a significant loss of elongation occurred in corn starch containing PE film which could be due to interactions between the film and free radicals developed during lipid oxidation in ground beef during frozen storage. Inconsistent results were found when packaging broccoli and bread in corn starch film. Therefore, Holton et al . (1994) recommended that corn starch based PE film be used only for packaging of wet and dry low-lipid foods. However, they discouraged use of the film for high fat content foods due to possible interactions between the film and free radicals derived from lipid oxidation. Strantz and Zottola (1992) and Kim and Pometto III (1994) evaluated the survival of bacteria on beef and bologna packaged in a corn starch containing PE film . Starch addition (0±28%) did not impair heat-sealing, nor did it accelerate microbial growth in ground beef. Additionally, colour stability during refrigerated and frozen storage was not affected. The mechanical properties of the films used for packaging of ground beef were not significantly changed after refrigerated or frozen storage . Strantz and Zottola (1992) inoculated lean beef and bologna with Sal-monella typhimurium ,Bacillus cereus ,and Staphylo-coccus aureus and found that bacterial growth and survival were not enhanced by the presence of corn starch (6%). They also examined the migration of the same bacteria by inoculating the exterior of the packaging material with bacteria and found no migration of bacteria through either the PE film or the corn starch containing PE film. Both studies established that the microbiological quality of the foods was not affected by the presence of corn starch in PE films; this leads to the conclusion that corn starch containing PE films have true potential as primary food containers for selected products.

In Belgium, packaging containing starch is used commercially for fast-food packaging of French fries. Other applications include disposable food service items and paper coatings .The R&D activities within the polylactate and polyalkanoate fields have been intensified during the last decade, and packaging materials are now readily available. In the case of both polylactate and polyalkanoate based packaging, a lack of published scientific studies is very evident. However, Danone, a dairy company, is presently testing the use of polylactate based cups for yoghurt packaging. Other potential commercial applications of polylactate based materials also include disposable food service items and bags (for example, bakery products). With respect to polyalkanoate, suggested use within the food sector includes beverage bottles, coated paperboard milk cartons, cups, fast food packaging, and films . More recently, French researchers have demonstrated that the use of gluten films may actually be advantageous for storage of respiring fresh produce . The gluten-based film had suitable O2 barriers while remaining sufficiently permeable to carbon dioxide. Thus, a modified atmosphere containing 2±3% O2 and 2±3% CO2 was developed, which the authors claim is favorable to the overall quality of mushrooms.

Future use of biopackaging for foods Many food products are unsuited for bio-based packaging as it exists. It is, therefore, important to identify foods suitable for these packaging materials. Furthermore, the manufacture of bio-based packaging is considerably more expensive than the production of traditional packaging, i.e. polyethylene (PE), as the bio-based materials are often produced batch-wise in small-scale operations. Another important issue is public opinion. It is generally accepted that consumers should be more conscious of the environment. Hence, it would be considered environmentally friendly to buy foods in biopackaging based on renewable resources. Consumers are probably willing to pay more for an environmentally friendly product, and this has to be taken into account when selecting the food products for bio-based packaging. In addition, bio based packaging for foods may provide new possibilities for modified atmosphere packaging (MAP). Bio based packaging may provide new atmosphere conditions, which improve the quality of specific food products during shelf life (e.g. vegetables). It appears that the barrier properties of bio packaging materials, in particular the moisture barrier properties, are inferior to existing packaging materials. This is particularly true when bio-based packaging is used as primary packaging. This problem can be solved in different ways. The immediate solution is to package foods that are compatible with the materials and their properties. However, it is also possible to use an edible coating with the required barrier properties for the food and subsequently use the bio based materials as primary packaging. The primary packaging material may be produced from mono materials which are favoured in terms of source collection. This also minimizes the amount of packaging material used. Coating of the bio-based material could also be an option; the coating could, for example, be wax which would add hydrophobicity to the packaging material. Technology also makes it possible to laminate two bio-based materials together or design a laminate with bio-based materials mixed with synthetic materials. Finally, a secondary packaging, not bio-based, may be used. It may be necessary to modify the bio-based materials to improve their properties with respect to food packaging. This will naturally increase the price of the end product, due to, for example expenses for research and development of the optimal modification of the material. The price level of the packaging material also depends on the production scale. A lower price is anticipated in the case of large-scale production. Migration is another important factor in food packaging. Before using bio-based packaging material as a primary packaging material for foods, migration (overall and specific) must be researched in order to avoid harmful substances migrating to the food product in contact with the packaging. Active edible coatings or bio-based materials where migration of e.g. antioxidants and anti-microbial compounds is desired also must meet the legal requirements, and this must again be tested thoroughly. Many bio-based food packaging materials are biodegradable. Thus, the microbial stability of the material during storage until disposal must be tested before using the material as a primary packaging material for foods (legislation about relevant compounds is needed, compounds used in the production (additives and plasticizers) must be approved). The authors do see possibilities in using bio-based packaging for food both in the immediate and remote future. There are still a few obstacles in the way before this can become a reality. The western consumers demand high quality food products, and they are increasingly aware of environmental issues. Consumers find not only the origin and treatment of the food important, but also the disposal of the food packaging. If consumers find the food satisfactory, they are willing to pay more. Indeed, recent consumer surveys show that the consumers are willing to pay more for food packaged in bio-based materials which are more friendly to the environment . Therefore, biopackaging of organic foods is a possibility, because they are typically more exclusive and expensive. Another food group suitable for bio-based packaging is ``high value'' fruit and vegetables, e.g. mushrooms and minimally processed salads with short-shelf life. We believe it is important that bio-based materials have an image of something which comes from agricultural sources and biodegrades in nature, causing no harm to the environment. In connection with this, life cycle analyses (LCA) must be carried out for bio-based packaging materials. Legislation is another aspect that cannot be ignored. It is of vital importance to identify a standard way of labelling the material or package. This labelling should indicate that the packaging is based on renewable resources. This makes it easier for the consumers to differentiate between the various food products, and it facilitates sorting of the waste. Many European countries incinerate household waste. Systems could be developed where disposal of packaging for incineration is taxed, whereas no tax is imposed on compostable bio-based packaging made from renewable biodegradable resources. Additionally, standards must be made for the new types of bio-based packaging. Many of the compounds used to manufacture the bio-based packaging are not incorporated in the current legislation. The agricultural policy of the EU addresses the issue of using surplus stocks in Europe (mainly wheat and corn). In addition, a large amount of residual agricultural products has today no use, but could be a part of the production of e.g. polylactate (PLA).

Conclusion

Great possibilities exist for packaging in bio-based materials. However, further research within different areas of bio-packaging, e.g. legislation, processing technology, and compatibility studies of foods and packaging must be initiated before bio-based materials can be used for primary food packaging. It can be concluded that bio-based materials offer great potential for the packaging industry. It is however important to realize that a thorough evaluation of the functional properties of a bio-based material is essential before it can be used as an alternative for traditional film materials. . It can be concluded that bio-based materials offer great potential for the packaging industry. It is however important to realize that a thorough evaluation of the functional properties of a bio-based material is essential before it can be used as an alternative for traditional film materials.

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