ENVIRONMENT-FRIENDLY PACKAGING SOLUTIONS FOR ENHANCED STORAGE AND QUALITY OF SOUTHERN AFRICA'S FRUIT AND NUT EXPORTS

The ENVIROPAK project

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INTRODUCTION

Despite a high degree of sophistication in modern packaging and export technologies, such as multi-layered barrier plastics and oxygen scavenging containers, the losses in fruit and nut exports are high. Spoilage and downgrading of quality are commonly 20% and may be even higher. Many tropical fruits and nuts are not found on the European and American export markets due to difficulties in keeping the quality during transport, despite a growing demand for "exotic" foods. The EU-INCO funded project ENVIROPAK assumes a new approach to enhance the transportability of fruit and nuts through the use of edible coatings. The coatings are formed from the sorghum protein kafirin, thus promoting and strengthening the utilization of an important staple crop.

Many edible proteins and polysaccharides form materials with useful material properties. Materials from native proteins and polysaccharides generally have excellent gas barrier properties, good mechanical properties, and form appealing transparent materials, which are often even thermoplastic. So do conventional, petroleum- based plastics, and a broad comparison of biopolymers vs. petroleum based polymers is appropriate in order to motivate the use of edible coatings as a packaging alternative.

Biopolymers are environment-friendly. Biopolymers are derived from renewable resources and therefore produce no net increase in atmospheric CO_2. As part of a sustainable material cycle, the biopolymer can, in contrast to petroleum-based materials, be produced at a low cost in any country, and is therefore also economically sustainable. Biopolymers are biodegradable, unless heavily modified, and can be composted, thus promoting an environment-friendly waste management system.

Biopolymers are abundant. In the year 2000 the global production of oil was 3.59 Gton, of which 4% was used for plastics, rendering 160 Mton annually[1, 2]. This is a small amount compared to the available biomass which could be used for biopolymer materials. The global production of crop by-products was, for instance, 2.7 Gton in the year 2000. Compare this with the total available phytomass mass globally, estimated to be 13 Gton annually[3]. The production of specific, pure biopolymers is significantly lower, with the exception of cellulose fibres and starch. The total potential mass of starch from cereals is about 1.2 Gton annually[1]. Considering that cereal carbohydrates are currently used for food and feed, the amount available for material application is limited. But even a small fraction of the total production yields considerable amounts, which could possibly compete with commodity polymers, and certainly with speciality polymers. The acceptance for non-food use differs widely, with the EU having a surplus of crops and the developing countries needing all edible biopolymers primarily for food and feed.

Biopolymers are inexpensive. Starch costs about 0.3 Euro/kg and is available in large amounts in pure form. Several corporations are also initiating large-scale production of polylactic acid (PLA). The PLA is produced from crops, and the estimated price is 1-2 Euro/kg when it is available in large amounts on the market. This can be compared with the price for conventional plastics in bulk at 0.5-1 Euro/kg (polyethylene PE, polyvinylchloride PVC, polystyrene PS e.t.c.). Despite the low raw material price for starch, there is to my knowledge no starch-based plastic available on the market for less than 3 Euro/kg. The high conversion cost for starch is remarkable. Other edible biopolymers such as gelatine, alginate and xanthan all cost 3-10 Euro/kg. There is also on-going work to utilize crop by-products for biomaterial production such as in the Enviropak project.

Biopolymers have unique functionality. The hydrophilic character of biopolymers, especially edible biopolymers, provides biodegradability as well as good gas barrier properties. The mechanical strength is comparable to that of petroleum-based polymers. The edibility is a unique feature. All of this makes biopolymers competitive in niche applications such as biodegradable packaging and utensils, edible coatings and dissolvable plastics.

Edible materials are well suited for food applications, especially as edible coatings. Wax has been used as a coating on fruit, at least since the 12th century, to reduce moisture loss[4]. Other reported uses include oxidation barriers such as alginate coatings on fish[5], zein on pork[6] and tomatoes[7] and whey protein on peanuts[8]. These are passive applications, but there are also reports of active food applications where coatings are used as release carriers. Coatings containing preservatives have been used to prevent proliferation of microorganisms on the surface. Cellulose-based coatings containing organic acids were claimed to prevent growth of microorganisms in general on meat[9], and alginate coatings containing organic acids were shown specifically to prevent proliferation of Listeria monocytogenes on beef[10]. Edible coatings of gelatine containing anti-oxidants on turkey were early shown to decrease lipid oxidation[11].

Edible coatings are also applied to pharmaceutical products both as a controlled-release device and in a passive function to mask an unpleasant taste (e.g. in ibuprofen), or to improve shelf-life stability (e.g. in conjugated estrogens)[12]. At the moment, much attention is being focused on improving existing coating materials as well as exploring new materials. New polymers for controlled-release applications are being synthesised or modified from existing biopolymers[13-15].

THE ENVIROPAK PROJECT

The Enviropak project is aimed at utilizing the inexpensive, renewable raw materials which are by-products of southern Africa's indigenous sorghum cereal industry to develop and manufacture novel, high value edible coatings and films. These are used to improve the quality and shelf-life of the fruits and nuts, which are important export products for southern Africa.

Edible coatings and films are not only environment-friendly packaging solutions, they can be effective in inhibiting migration of moisture, oxygen, carbon dioxide, aromas and lipids; to carry food ingredients (e.g. antioxidants, anti-microbials, flavours); and improve mechanical integrity or handling characteristics of the food. In other words, they help to maintain and improve quality and extend shelf life of the coated products.

Sorghum is indigenous to the semi-arid tropics of Africa and is much better suited to cultivation than non-indigenous cereals, such as wheat or maize[16]. It will consistently produce a crop under conditions where other crops fail, thus it is a critically important crop in this region, especially for those people who live in the semi-arid under-developed areas where food security and supply remains a serious problem. The southern African sorghum cereal industry is well-developed. However, because of problems associated with the processing of sorghum, large quantities of protein-rich by-products, today regarded as waste, are produced (more than 30 000 tonnes annually). From recent findings it is believed that kafirin, and thus the by-product material, has outstanding potential for edible food and film barriers[16].

The participants in the ENVIROPAK project and their respective competences are summarised in the table below.

Partner	Country	Scientific leader	Competence area
SIK – The Swedish Institute for Food and Biotechnology	Sweden	Mats Stading	Food physics and edible packaging
IMCB – Institute of Composite Materials Technology	Italy	Salvatore Iannace	Thermoplastic processing of biopolymers
IFR – Institute of Food Research	UK	Peter Belton	Molecular structure/ function relationships
CSIR	South Africa	Janice Dewar	Sorgum science, protein extraction and fruit processing
University of Pretoria	South Africa	John Taylor	Cereal protein, food chemistry and fruit processing
University Eduardo Mondlane	Mozambique	Maida Khan	Process engineering and nut characteristics
University of Mauritius	Mauritius	Saheed Goburdhun	Tropical fruit post-harvest technology

Table 1. Participants in the ENVIROPAK project

Figure 1. Red sorghum (Courtesy of J. R. N. Taylor, University of Pretoria)

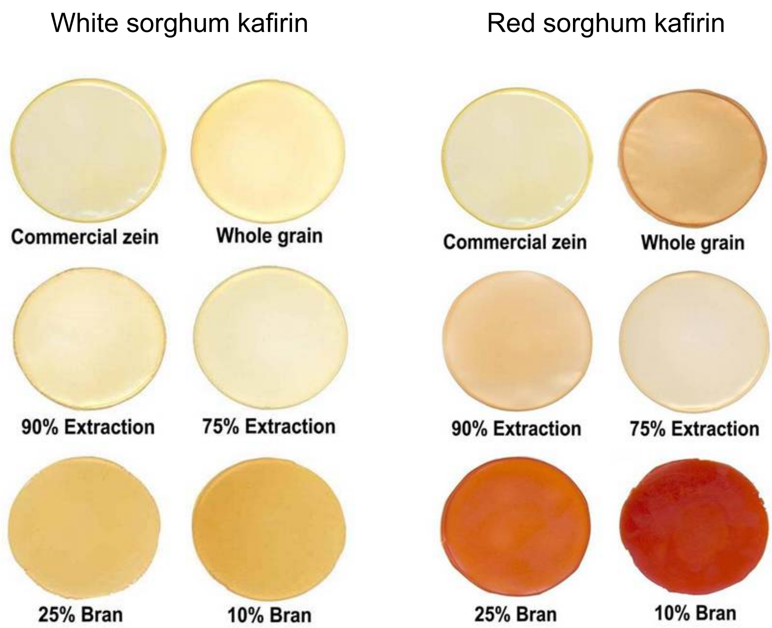

Figure. 2. Examples of cast kafirin films from different milling fractions of white and red sorghum as compared to cast films of zein. (Courtesy of L. da Silva and J. R. N. Taylor, University of Pretoria)

FUTURE PROSPECTS

A successful completion of the project would lead to the creation of local industries isolating kafirin protein and potentially, manufacturing plant-based edible coatings and films and biodegradable packaging with unique functional properties. These industries would create employment not only through the manufacture of edible films and coatings and biodegradable food packaging, but upstream to the small-scale sorghum farmers and small-scale sorghum processors, and downstream though helping the growth of southern Africa's export fruit and nut industries. The technology developed with regard to nuts should help Mozambique revitalise its export nut industry that has been virtually destroyed during the years of Civil War.

The project also has potential for the alleviation of poverty, particularly in the rural areas. Opportunities exist for several thousand small-scale millers and brewers, to generate more income and jobs from their existing small businesses and also to create new small, medium and micro enterprises geared at kafirin protein concentration. Considering the project emphasis on developing coating technologies specifically at small scale, opportunities will also exist for creating small businesses in this area.

By beneficiating by-products of the indigenous sorghum industry this should help make the industry more competitive and ensure its survival, thereby preserving jobs. Similarly, previously disadvantaged farmers should find an increased demand for their sorghum crop and by extending the demand for an indigenous cereal that is well adapted to the harsh African conditions, will aid food security in the region. The development and ultimate production of biodegradable packaging products from renewable resources (i.e. cereal polymers) will help replace environment-unfriendly plastic packaging and thereby combat the ever-increasing problem of environmental pollution and promote sustainable packaging solutions. Kafirin is produced from bran, which is a waste product. The protein content is 15% which would mean a direct waste reduction of 1500 tons in the dry milling industry of South Africa alone. After exploitation of the results further waste streams could be utilized e.g. from the sorghum brewery industry. The overall environment impact is consequently very positive.

The technology will primarily be developed for African fruit and nut products and it will be adapted to African conditions. It may, however, be further developed and adapted to European food products and may therefore also benefit European food industry.

RESULTS AND DISCUSSION

The ENVIROPAK project started 2002 and there are consequently so far few published results to show. I will therefore focus on general properties of biopolymer films with some specific details on kafirin films. More detailed results on the thermoplastic properties of cereal protein films will be presented in the paper by Emmambux, Iannace and Stading.

Biopolymer films from unmodified proteins and polysaccharides are moisture sensitive since water acts as a plasticizer for the dry films and swells intermediate moisture systems[17]. The water plasticization effects the structure of the films which in turn impairs both mechanical and barrier properties. The action of water on the meso-scopic scale can be exemplified by films of amylose. Leloup and co-workers have proposed a model for the network of the amylose gel which is assumed similar to the film where a network strand consists of associated blocks of double helices aligned along the strand, almost perpendicular to the length axis of the strand[18]. Loops of amorphous amylose would be found around the strands and at the cross-links, thus linking the helices. Building on this model, the water sensitivity of amylose gels can be explained as follows[19]: When the surrounding humidity rises the amylose film takes up water, which then plasticizes the amorphous areas of the amylose network. Since the amorphous areas are found mainly at the cross-links, the plasticization leads to a more flexible network, allowing rearrangement of the network structure. On a further increase in the surrounding humidity, the network will take up more water and swell. The elasticity of the strands is not completely homogeneous throughout the network, and thus the structure becomes heterogeneous due to the swelling pressure. Open areas with large pores and denser areas with smaller pores are formed as shown in Fig. 3. The plasticization and swelling are reversible, and both mechanical and barrier properties are restored on decrease in surrounding humidity.

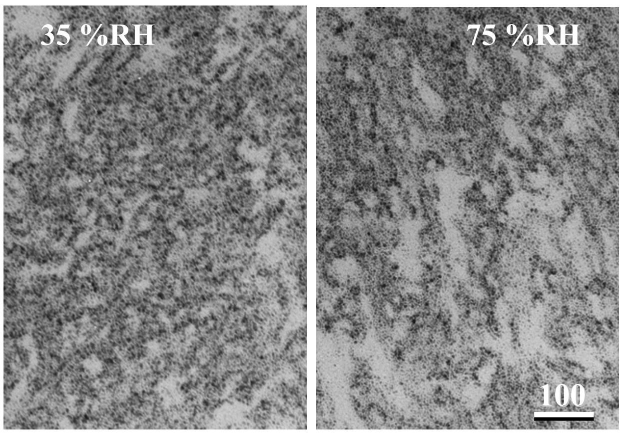

Figure 3. TEM images of sections of amylose films with glycerol/amylose=0.4 (w/w) conditioned at surrounding relative humidities of 35% and 75% respectively[19].

The change in microstructure caused by an increase in surrounding humidity also causes impaired mechanical and barrier properties, as shown in Fig. 4. There is a distinct increase in oxygen permeability at 70% relative humidity (RH) coinciding with W_g, as shown by the peak in phase angle[19, 20]. We have noted that other films from native biopolymer also lose their properties at about 70 %RH or higher. The loss of functional properties at high RH is a serious disadvantage in applications such as food packaging or disposables. Most foods needing gas barriers in the packaging have water activities well above 0.7 and would thus interact negatively with the biopolymer material.

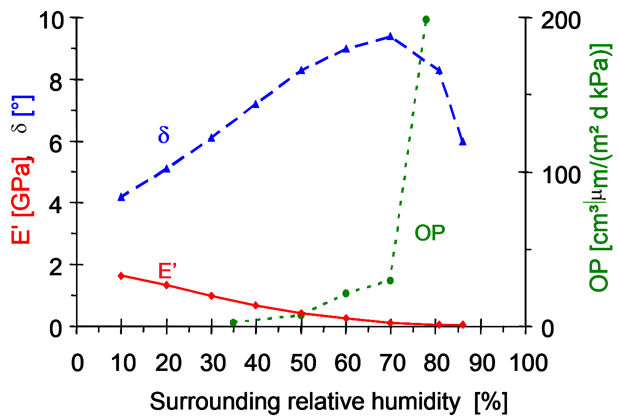

Figure 4. Storage modulus E', phase angle δ and oxygen permeability, OP, of a glycerol plasticized amylose film (glycerol/amylose=0.4) as a function of surrounding relative humidity.

Kafirin has the advantage of being more hydrophobic than amylose thus forming films which are less sensitive to moisture. A commonly used indicator for the moisture sensitivity is the water vapour permeability (WVP) which is usually measured by a gravimetric method (ASTM E96) giving the transmission rate of water vapour through a sample film[21]. The WVP for kafirin films is given in Figure 5 together with WVP for starch based films and whey protein films as a comparison. Kafirin has a much lower WVP than whey protein and slightly lower WVP than starch based films. The water vapour permeability does not give the full picture of moisture sensitivity since it only reflects the early plasticization and not the swelling. A kafirin film which is immersed in water swells but retains it mechanical integrity whereas an amylopectin film quickly dissolves.

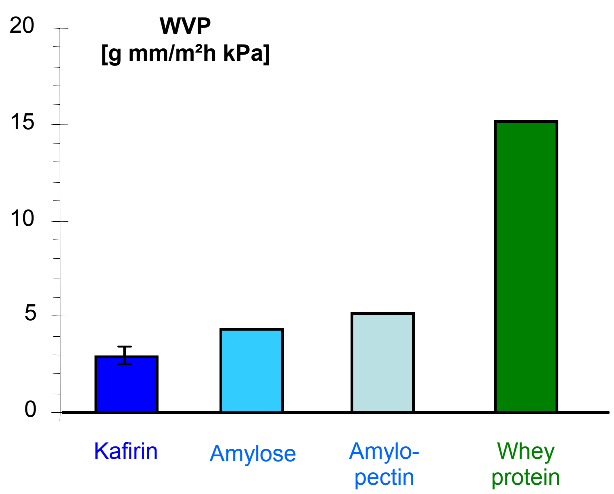

Figure 5. Water vapour permeability of some biopolymer films including kafirin.

CONCLUSIONS

Edible biopolymers are competitive both as commodity polymers and in speciality applications where a specific functionality is valued. In a scenario where petroleum-based polymers are replaced by biopolymers, edible biopolymers from food crops would primarily be used in food applications, whereas other biopolymers could well cover the demand for commodity polymers. The functionality of coatings made from edible biopolymers has been verified regarding mechanical, gas barrier properties and release of additives. The last question remaining is why biopolymers in general are found in so few commercial applications considering their benefits? The answer is that in most applications biopolymers are currently still too expensive for the functionality gained compared with petroleum-based polymers due to the high conversion cost and small amounts available. A continued development of functionality and processing is needed for a commercial break-through. The ENVIROPAK project therefore has a good potential for delivering scientific results which are useful in commercial applications.

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