SUSTAINABLE INNOVATIONS AND APPROACHES FOR TRANSITIONING TOWARDS PLASTIC-FREE LIVING

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Abstract: *Current study presents the research and development of sustainable biomaterials used for packaging or ecodesign purposes. Three sustainable biopolymers - nanocellulose, chitosan and alginate- and two of their respective combinations have been screened for mechanical, barrier and morphological properties. Moreover, the sources of the biopolymers from the food production waste have been investigated and proof of concept for their usage has been confirmed. Obtained results have confirmed the flexibility in formulation of foil properties covering a large spectrum of applications. The potential for the usage of the food waste biopolymer materials, their versatility in application in the packaging industries together with their low environmental impact and a competitive market price based on techno-economical analysis for the scaling up of the production, has been considered.*

Keywords: biopolymer foils, sustainable biomaterials, packaging, food waste valorization, technoeconomical analysis

1 INTRODUCTION

Plastic bags have become the modern symbol of the consumer waste. Plastic is a convenient material because it is cheap, versatile and helps to reduce the amount of food waste. However, it is also linked to the toxicity, microplastics, fossil fuels, and eventually - to the climate change. While plastics are not the sole culprits in the modern solid waste crisis, they are the most visible components (Novak et al., 2020). Despite the recent increase in consumption of single use plastics caused by the Covid-19 pandemic, the number of people who are turning towards sustainable brands continue to grow with every year. Even though packaging makes up a small part of a product's environmental impact, it is the first thing that the consumers see, and it can heavily influence their buying decisions. CGS 2020 Retail and Fashion sustainability Survey has shown that only 27% of the customers would not factor sustainability into their buying decisions (CGS, 2000). Therefore, the the packaging industry has started to shift towards more sustainable materials. Generation Z (people born between 1997 and 2015) care more about sustainability than the previous generations and are more likely to pay more and stay loyal to brands with sustainable options (CGS, 2020). Therefore, the new generation of sustainable biomaterials should not only have the same properties as petrol-based plastics without having the heavy cost on the planet but should also comply to the same aesthetic standards as conventional materials and should feel good to the touch (Lavrič et al., 2021). They should be easily recyclable, biodegradable, or compostable in the home compost (Oberlintner et. al, 2021). To answer to all these requirements, we have created a range of biomaterials made of food waste source or biomass. They can be sourced from discarded shrimp shells (Bajić et. al, 2019) or fuit fibers (vegan/ cruelty-free option) (FruitFibers.com) and can be made in different colours.

2 MATERIAL AND METHODS

2. 1 Biomaterial preparation

Materials and methods of biopolymer and foil preparation have been described previously (Lavrič, et. al, 2021; Bajić, et. al, 2019; Novak et. al, 2020). Due to the secret know-how, some of the biomaterial formulations cannot be shared.

2. 2 Mechanical properties and thickness

Moisture content (MC) was analyzed with HE53 Moisture Analyzer (Mettler Toledo, United States). The thickness of the films was measured with ABS Digital Thickness Gauge (Mitutoyo, Aurora, USA). Tensile strength and elongation at break were measured according to the guidelines of the American Society for Testing and Materials (ASTM) D 882 standard method (ASTM C1147-D359).

2. 3 Barrier properties

Water Vapour Transmission Rate (WVTR) was performed according to ISO 2528:2018 (23 °C and 50% RH). Oxygen permeability (OTR) were tested using standard ISO-2:2003 (23 °C and 50% RH).

3 RESULTS

In recent years, to accommodate the trends of bioeconomy transitioning towards circular economy with the goal of moving towards zero waste economy, biopolymers have been explored as the fossil fuel-based plastic alternatives. In Figure 1 some of the recent sustainable innovations and approaches for transition to plastic-free living have been presented.

Figure 1: New generation of biopolymer-based material prototypes. Upper row illustrates new types of plant-based textiles made of discarded food waste. Bottom row depicts zero-waste and active film packaging intended for food and drinks.

One of the important characteristics for the material is its high strength together with the ability to stretch. In Figure 2 tensile strength and elongation at break for water-soluble alginate foils is presented.

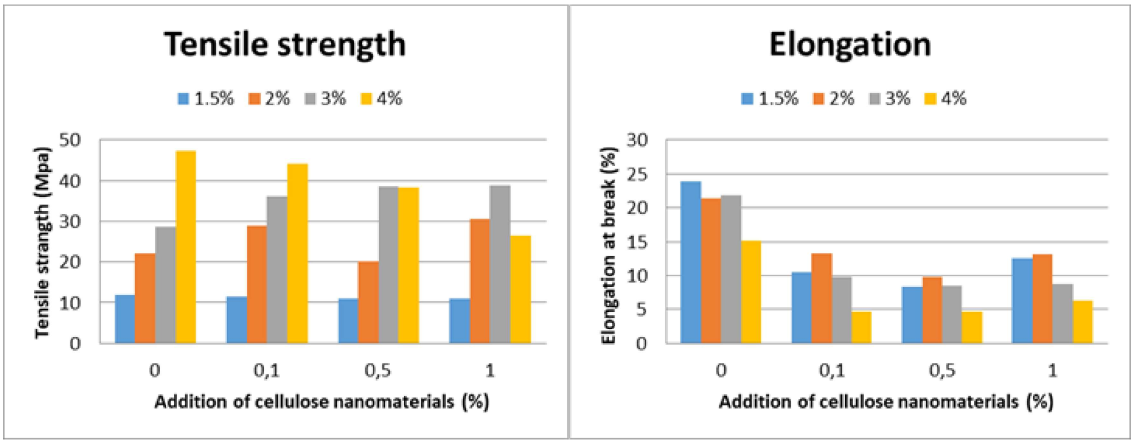

Figure 2: Tensile strength and elongation at break for water-soluble alginate foils. Foils were prepared with 1.5%, 2%, 3% or 4% of alginate in a starting film forming solution with addition of different amount of cellulose nanomaterials.

As expected, higher percentage of alginate biopolymer improves the mechanical properties of the material. The addition of cellulose nanomaterials shows some positive effect on the barrier properties of the foils (Figure 3).

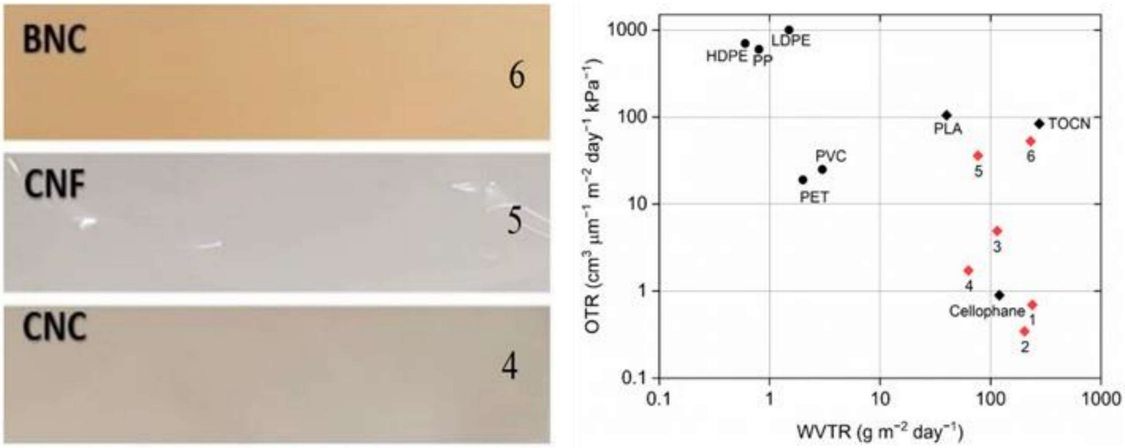

Figure 3: Biopolymer foil visualization (film 4,5,6) and an overview of WVTR and OTR of some synthetic polymers compared to our nanocomposite packaging films (adapted from Lavrič et. Al, 2021). Black circles- petroleum-based polymers, black diamonds- commercial biopolymers, red diamond- biopolymer nanocomposites. HDPE- high-density polyethylene; LDPE- low-density polyethylene; PP- polypropylene; PVC- polyvinyl chloride; PET- polyethylene terephthalate; PLA- polylactic acid; TOCN- TEMPO-oxidized cellulose nanofibers.

Three types of cellulose nanomaterials as well as the combinations of different biopolymers such as alginate or chitosan have been tested. OTR and WVTR have been compared to commercially available materials, showing high oxygen barrier for all biomaterials studied. Cellulose nanomaterial biocomposites (Film 4,5,6) had slightly improved WVTR properties compared to single biopolymer foils. Finally, the overall acceptance of the new biomaterial is always based on the techno-economical evaluation. In Table 1 the simulation of the prices for three types of advanced biodegradable and recyclable biomaterials is shown.

Table 2: Simulation of the prices for three selected types of foil packaging biomaterials based on the achieved TRL.

Biomaterial	***Biopolymer source***	***Cost of the materials at TRL 5***	***Cost of the material at TRL 7-8***
Active packaging	*Chitosan with plant extract*	*7 €/m^2 or 90 €/kg*	*2.1 €/m^2 or 27 €/kg*
Zero-waste packaging (water-soluble)	*Seaweed biopolymer*	*3.6 €/m^2 or 45 €/kg*	*0.9 €/m^2 or 16 €/kg*
Zero-waste packaging bionanocomposite	*Seaweed biopolymer with cellulose nanomaterials*	*5 €/m^2 or 54 €/kg*	*1.5 €/m^2 or 21 €/kg*

In term of the value, the product is more important than its packaging. Therefore, the extended shelf life of the packed goods can help to reduce the food waste and, hence, the cost of the product, which is much greater than the cost of their respective packaging foils. While the cost of the biomaterial foils compared to conventional plastic foils (PP, PE) is at least 10-fold higher, these plastic alternatives should be compared to more advanced packaging solutions due to some advanced properties, which a single-layer plastic foils do not have. In addition, the full values in term of disposal and environmental taxes for unsustainable materials after their disposal by the end user should also be taken into consideration.

4 CONCLUSIONS

In the current study, some details of the sustainable biopolymer-based applications, which are minimizing the amount of waste sent to the landfill while fulfilling the same purposes as conventionally used packaging materials, have been presented. For a broader acceptance of the new generation of biomaterials, a complete life cycle assessmet should be performed together with the single-use plastics or other petrol-based composite materials.

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