FOOD PACKAGING FROM NATURE: CELLULOSIC FILMS FOR THE 21ST CENTURY

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This spring, I had the privilege of receiving an invitation to present my PhD research at The STEM for Britain Poster Competition held at the Houses of Parliament. Amidst the remarkable array of diverse and groundbreaking research, I was thrilled that my poster received two awards: the Gold award in the Physics category and the Silver award for the Dyson Sustainability Awards. This experience has been truly unparalleled for me as an early-career scientist, instilling a confidence in my own abilities and alleviating the daunting challenge of combating the notorious 'Imposter Syndrome'.

My PhD research is based in the Soft Matter Physics Group at the University of Leeds. 'What is Soft Matter Physics?' you might ask. Without running the risk of sounding too scholarly; I like to call it: 'The Science of things that are Soft'…. frustratingly vague, I know. This field explores a wide range of materials including polymers, colloids, liquid crystals, rubbers, foams, and more. We use physical, mathematical, and chemical sciences, to explain phenomena exhibited by materials in our everyday lives [1]. What makes my PhD even more exciting is collaboration with industry giants, Futamura; the world's leading producer of cellulose films. This dynamic partnership between academia and industry has enabled the privilege of visiting their UK factory, using their facilities, and forging excellent friendships and mentorships with their staff, creating an environment of lively discussion (and debate!) during meetings. By employing academic resources, I am able to address real-life problems, which, in my opinion, embodies the true essence of scientific pursuit that we all yearn for.

Ok, so what problems are we talking about then? Well perhaps the biggest problem that my generation will have to face. How can we sustain and enable a developed lifestyle worldwide to our growing population with our finite resources? One critical aspect of this global challenge lies in our escalating plastic consumption. We are rapidly approaching the threshold of plastic consumption that our planet can sustain and the reckless overuse of synthetic plastics has become a focal point for climate activists. The packaging industry alone contributes a staggering 141 million tons of plastic packaging annually, accounting for up to 36% of total plastic pollution[2]. Synthetic plastics, derived from fossil-based resources, have dominated the field of material sciences throughout the past century, providing innovative and functional solutions for a wide range of applications. However, due to the limited nature of this resource, coupled with the fact that many synthetic polymers are non-biodegradable, there is an imperative drive for a more sustainable alternative.

One solution to address the issue of plastic pollution lies in the development of biodegradable materials; and where better to look for these than in nature? One such resource that is paving the way in this objective is cellulose, the main chemical component in most plants; making it Earth's most abundant organic polymer, constituting 1.5 trillion tons of the planet's annual biomass[3]. Cellulose is a linear chain polymer composed of 1000s of glucopyranosyl units, as illustrated in Figure 1, linked together[4]. Cellulose can be extracted from plants and converted to films using a technique known as 'The Viscose Process'. These biofilms possess high tensile strength and excellent barrier properties, making them well-suited for food packaging applications. These films are seeing a real resurgence in popularity as we instigate the phasing out of synthetic plastics for alternatives that are biodegradable and renewable.

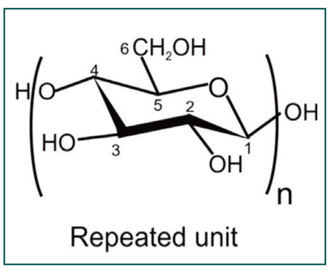


Figure 1: Cellulose monomer unit

Ok, so what's the catch? Well, one inherent obstacle with the wide-scale commercialisation of this process is that plants are capricious creatures, exhibiting a vast range of physical properties from one species to another. The architecture of the plant cell wall exists as a complex and varied blend of cellulose, hemicelluloses, pectin and lignin; whose combination has been optimised for individual plant's needs by nature over millions of years. The symbiotic relationship between each of these components is key to understanding a plant's (and their derived product's) mechanical, structural and biological traits. However, due to the vast divergences in cell wall structure between plant species, a comprehensive understanding of the relationships that drive a plant's characteristics remains elusive. This knowledge is vital in the drive for unlimited utilisation of plants for endless applications in the materials and agricultural industries, in order to accelerate the switch to renewable and biodegradable materials.

The research I presented at STEM for Britain focused on the properties of two cellulose-based films made using the exact same process and conditions, with the only difference being the starting wood pulp was derived from two different plant species: Eucalyptus and Western Hemlock. The aim was to understand how variation in plant species affects the mechanical and structural properties of the films. This project was particularly engaging as it stemmed from genuine customer complaints regarding the underperformance of Hemlock films. By identifying the structural properties that impact film performance, we can provide insights for Futamura to enhance their manufacturing process and ensure consistent films.

In order do this, I applied a range of physical analysis techniques; including:

- **Tensile tests** determined mechanical performance and confirmed customer complaints that the Western Hemlock Film was underperforming.
- **Dynamic Mechanical Thermal Analysis** determined the molecular motion of the cellulose molecule within the films. These tests showed that the molecular dynamics of cellulose was consistent for both films, suggesting that this is not affecting mechanical properties.
- **Vacuum oven testing** and purging under a nitrogen atmosphere discovered that the Eucalyptus film has a higher water content. This result is associated with superior mechanical properties due to the way that water interacts with the various side groups on the cellulose molecule, resulting in increased ductility.
- **Enzyme Linked Immunosorbent Assays** found that the Eucalyptus film contains a higher composition of the

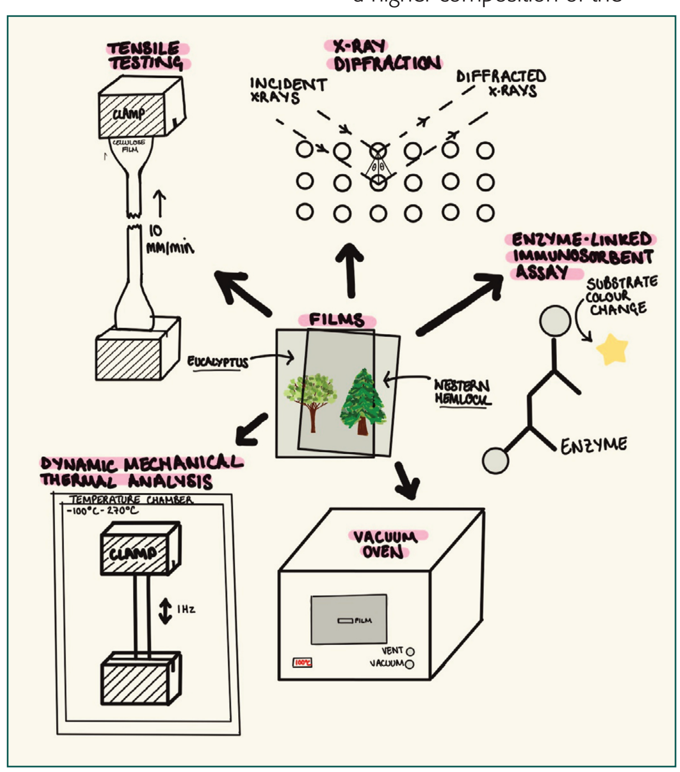


Figure 2: Schematic summary of physical analysis techniques

hemicellulose 'Xyloglucan', this compound is associated with increasing the water content of cellulosic-materials, thus altering the mechanical properties of the films this way.

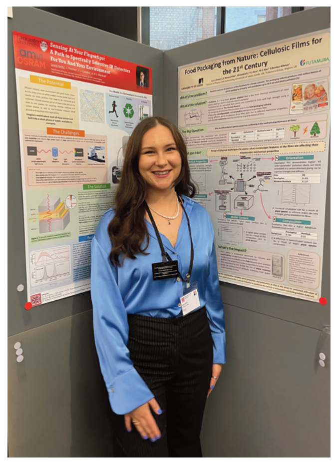
- **X-Ray Diffraction analysis** determined that the orientation on cellulose chains in the eucalyptus film was higher, this can be a result of the length of the cellulose chain in the original plant material and is also associated with superior mechanical properties.

To summarise, my work has shown that the choice of plant species has an impact on the water content, composition and orientation of films, thus influencing their mechanical performance. This work has led Futamura to discontinue usage of Western Hemlock wood pulp, as well as incorporating Eucalyptus into all films to enhance mechanical properties. Ultimately, we want to understand the relationships between each of these structural and mechanical properties to enable the use of any plant species to create an optimally tuned, uniform film. Plant choice is deliberated extensively by industry; with sustainability and cost being extremely important factors. Continued research will enable the possibility of using agricultural waste feedstocks, improving Futamura's green credentials even further.

Earlier this year I had the chance to present this work at The Houses of Parliament for STEM for Britain competition. Being in my final year, I thought I had overcome the pre-conference nerves, known well to PhD students. However, as I approached Big Ben along Westminster Bridge, the stature of this event truly struck me. This was a pivotal moment, I remember thinking 'Ok, this is sink or swim' – a chance to share my obscure corner of research to a wider, and influential audience. The poster session ran for around 1.5 hours, with each judge offering a different perspective on my poster, creating a dynamic (and challenging) session of presentations, questions and defending! In between judges I chatted with the fellow students around me, the sheer range of outstanding research showcased from various institutions was truly staggering. The whole room vibrated with the buzz of scientific interest, creating an electrifying atmosphere. This was the most significant take away from the event, the passion for sharing research with an engaged audience is any researcher's dream. Once judging was over, I was visited by my local MPs; Hilary Benn and Alex Sobel. Their support and genuine interest provided me with a much-needed reset after an intense judging process. To have encouragement from Leeds representatives, really reinforced the value and importance of my research.

Announcement of the winners was accompanied with inspiring talks from MP Stephen Metcalfe and representatives from esteemed professional bodies. During the Physics awards, Dr Elizabeth Cunningham from the IOP spoke about the breadth of research that she'd encountered that day, as well as her own experiences at STEM for Britain.

Cliché, I know, but I had to do a double (and then a triple) take when she read my name for Gold in Physics. Amongst the phenomenal work I had seen throughout the session, I was honoured to be selected as the winner. We were recognised with certificates, medals and an enthusiastic photo shoot – my supervisors commented they had never seen someone smile with their whole body like I do in these photos. Once this had just started to sink in, it was time to announce the Dyson



Sustainability Awards for Outstanding Research towards a more Sustainable Future. Dyson representative, Nicola Clifton, announced that I had also won Silver in this category. So, overwhelmed with joy, I went up to once again to receive my certificate and prize! A PhD can be a thankless and often extremely lonely pursuit, however, these wins have been the ultimate recognition and culmination of all the labs, tests and tears.

The significance of this competition has been a defining moment in my academic journey. To stand with two other remarkable women as winners of a Physics award is a powerful testament to the progress we have made, something that my Grandma's would have dreamed to see. This experience has instilled a courage and fearlessness to pursue my work. I have been giving the elusive gift as a scientist of confidence to make bold and creative steps, alleviating the burden of self-doubt that most of us battle with daily. More importantly though, these awards highlight the significance of sustainability research and the advancement of materials. They signify the growing recognition within society of the importance of embracing sustainable solutions for a sustainable future. In the midst of all the challenges, the drive for the future of sustainability fuels my perseverance and dedication in my work, making me ever more relentless in my pursuit of knowledge.

Acknowledgements

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