Analysis of Degradation Pathways for a Biodegradable Plastic

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Introduction:

Degradable plastics (also known as polymers) have become an increasingly important focus in plastics research. Over the past few decades, scientists and society as a whole have become aware of the plastic waste issue developing globally. In the United States alone, almost 400 million tons of plastic are being produced each year, with 79% percent of that plastic ending up in the environment or landfills.[1] As a result, scientists are looking for ways to mitigate the long-term impacts of plastic on the environment.

One approach for alleviating the plastic waste issue focuses on developing plastics with the ability to break down using external stimuli. A stimulus of particular interest for this task is UV-light due to the control scientists have over it.[2] Light can be easily introduced and removed from a system. In addition, multiple variables can be changed, such as the wavelength of the light and the intensity of the light. Herein, we describe the analysis of a photodegradable plastic developed in our lab.

Previous work:

To date, significant progress has been made on this project. Previous students have been able to synthesize the desired stimuli-responsive plastic, poly(2-hydroxycinnamic acid) (**1**) from 2-hydroxycinnamic acid. Subsequently, they were also able to prove that the polymer was able to undergo degradation, forming coumarin (**2**) upon exposure to UV-light.

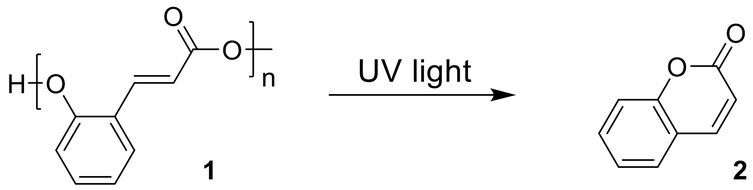


Figure 1. Image showing degradation of poly(hydroxycinnamic acid) (**1**) to form coumarin (**2**) when exposed to UV light.

Complete degradation of the stimuli-responsive plastic was demonstrated using a gel permeation chromatography (GPC) instrument. We were able to show that the polymer completely degraded over the period of 96 hours, producing coumarin as the product.

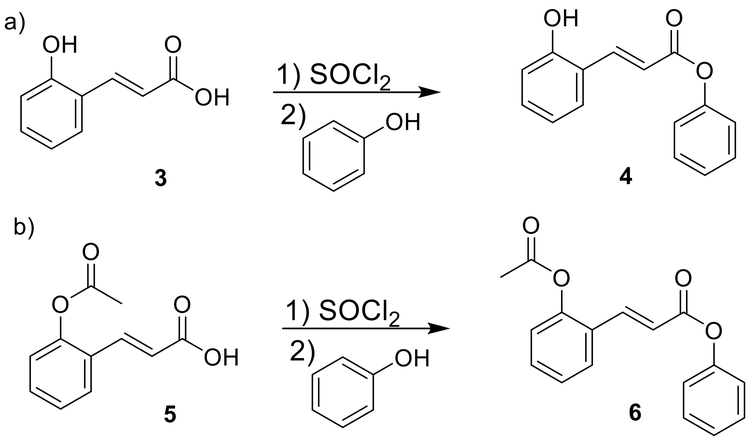
Our goal:

The goal of this project was to identify how this degradation occurs. Degradation of plastics generally occurs through one of two different paths, randomly throughout the chain or selectively from one end of the polymer to the other. In order to test the degradation of the polymer, we synthesized two control molecules, one that represents the structure at the end of the chain (**4**) and one that reflects the structure within the chain (**6**). Once those molecules have been synthesized, we will expose them to UV light to determine which, or if both, degrade.

Synthesis:

To create the control molecules, we converted a carboxylic acid to an acid chloride using thionyl chloride. Subsequently, phenol was added, completing the synthesis. For the control molecule representing the chain end, a free aryl alcohol is present (scheme 1a), and for the internal control molecule, the phenol is protected with an acetate group (figure 1b).

Scheme 1. Synthesis of poly(hydroxycinnamic acid)



Results:

Once the desired control molecules were synthesized, they were purified via column chromatography and characterized using nuclear magnetic resonance (NMR) imaging, as shown in figure 3. According to proton NMR, we were able to synthesize control molecules **4** and **6**.

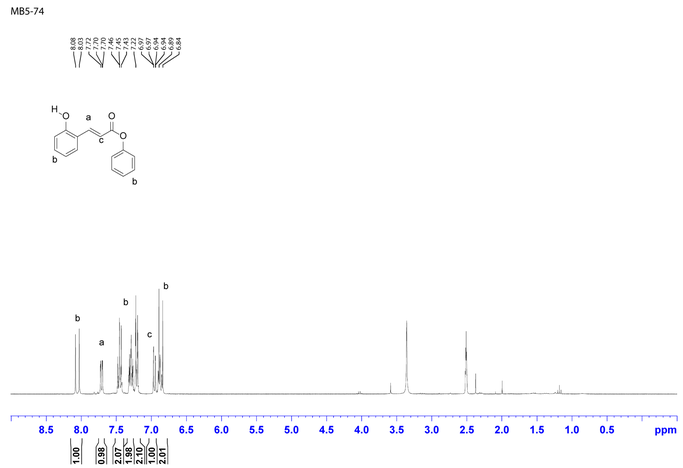


Figure 3. Proton NMR spectra showing the formation of our two control molecules, the free phenol and the protected phenol respectively.

Conclusion:

The synthesis of both control molecules was successful. We will now turn our attention to the degradation of these molecules upon exposure to UV-light and characterizing the outcomes.

References:

1) Geyer, R.; Jambeck, J. R.; Law, K. L. Scientific Advances, 2017, 3, e1700782.
2) J. Olejniczak, C.-J. Carling, and A. Almutairi, J. Control. Release, 2015, 219, 18-30; A. M. Kloxin, M. W. Tibbitt, A. M. Kasko, J. A. Fairbairn, and K. S. Anset, Adv. Mater. 2010, 22, 61-66.