EVALUATION OF PHENOLIC COMPOUNDS IN BIODEGRADABLE FILM BASED ON AGRICULTURAL BY-PRODUCTS USING THE HYPERSPECTRAL IMAGING TECHNIQUE

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ABSTRACT

Environmental sustainability and food safety concerns have driven innovation in food packaging, highlighting biodegradable and active packaging. Biodegradable packaging, made from natural materials like starches and cellulose, reduces plastic waste and can be enhanced with natural additives. Active packaging extends food shelf life and safety by releasing bioactive compounds such as antioxidants and antimicrobials. Phenolic compounds, known for their antioxidant and antimicrobial properties, are ideal for active packaging. This study used hyperspectral imaging to detect total phenolic compounds in biodegradable films. The Resonon Pika XC2 system captured spectral data, revealing significant concentrations of phenolic compounds unevenly distributed across the samples. Detailed spectral analysis identified specific wavelengths for phenolic reflectance, facilitating their quantification. These findings underscore the potential of hyperspectral imaging to optimize biodegradable film formulations and improve their functional properties, contributing to sustainable and safe food packaging solutions. Future research should focus on additional agricultural by-products and refining hyperspectral imaging techniques.

Keywords: Biodegradable packaging. Phenolic compounds. Hyperspectral Imaging. Pinhão failure. Rice husk.

1 INTRODUCTION

Growing concern about environmental sustainability and food safety has driven innovation in food packaging. Among the various emerging approaches, biodegradable and active packaging stand out, designed to minimize environmental impact and extend the shelf life of food [1].

Biodegradable packaging is a sustainable alternative to traditional synthetic polymers. Biodegradable packaging breaks down naturally from natural materials such as starches, cellulose, and proteins, reducing the accumulation of plastic waste in the environment. In addition to their ability to biodegrade, these packages can be enriched with natural additives that improve their functional properties, such as mechanical resistance and barriers against gases and humidity [2].

Active packaging goes beyond just containing products. It actively engages with the food, working to extend its shelf life and enhance its safety. This is achieved through the strategic release of bioactive compounds, such as antioxidants and antimicrobials, which combat spoilage and the growth of pathogens [3].

Phenolic compounds in various plants have demonstrated excellent antioxidant and antimicrobial capacity, making them ideal candidates for use in active packaging. These are a diverse class of natural products with potent antioxidant and antimicrobial activities. Their incorporation into packaging materials can prevent lipid oxidation and slow down microbial growth, extending the shelf life of food [4].

Hyperspectral imaging combines the benefits of spectroscopy with spatial information from imaging. It has been effectively used to quantify both internal and external attributes of various food products, including packaging [5]. Combining the power of imaging and spectroscopy allows for the acquisition of detailed spectral information from an object or scene [6]. Unlike traditional imaging methods, hyperspectral imaging can capture image data across Ultraviolet, Visible, Near infrared, and Short Wave infrared spectral bands. This spectral data provides much information that can be used to analyze and assess the quality, safety, and composition of products in a non-destructive and efficient manner [7].

Therefore, this work aimed to verify the possibility of detecting phenolic compounds in biodegradable food films using hyperspectral imaging.

2 MATERIAL & METHODS

Extraction procedure and film preparation: The aqueous extracts were prepared in a ratio of 1:10 (Pinhão failure or rice husk failure/distilled water) at 70 °C for 120 minutes under constant stirring. Then, filtration was performed to remove solids [4]. The film was prepared using the casting method with adaptations [8]. Edible materials were utilized, homogenizing 24 g corn starch, 400 mL distilled water, 13.3 g glycerol, 2.4 g carboxymethyl cellulose (CMC), and heated to 50°C with constant stirring for 15 minutes. The temperature was then raised to 80°C for 30 minutes to ensure complete gelatinization and film formation. Finally, at 90°C for 15 minutes, and then were added 20 mL rice husk extract and 150 mL Pinhão failure extract. The solution was poured into glass containers (0.08 $g.cm^{-2}$) and dried in a forced air circulation oven at 45°C for 24 hours.

Color and total polyphenolic: The coloration was determined with a sphere spectrophotometer (SP60, Lovibond); these values include L* (with white at 100 and black at 0), a* (red at +120 and green at -120), and b* (yellow at +120 and blue at -120) [9]. The polyphenolic was performed following the *Folin-Ciocalteu* method [10].

The hyperspectral image analysis of the biodegradable films was conducted using a Resonon® Pika XC2 hyperspectral imaging system. The system, equipped with a camera of 400-1000 nm wavelength range and light source, was calibrated using a white reference panel and set up with the camera on a stable platform and films on a motorized stage. Film samples were scanned at a spatial resolution of 0.1 mm per pixel under controlled lighting. The system captured reflectance data, producing a three-dimensional data cube with spatial and spectral information. Pre-processing was performed to correct spectral noise and background interference.

3 RESULTS & DISCUSSION

Hyperspectral image analysis of samples measuring approximately 3x5cm of biodegradable films demonstrated the presence and distribution of phenolic compounds. Figure 1a shows the RGB image of the biodegradable film. Spectral reflectance data obtained in the 400-1000 nm wavelength range allowed us to identify phenolic signatures, particularly at specific wavelengths associated with these compounds[11]. Within this range, specific wavelengths such as 430 nm, 550 nm, and 680 nm are often used to identify these compounds. The accuracy of these peaks varies depending on the specific type of phenolic compound and the matrix of the analyzed material[12].

Figure 1b shows a scalar image with a red color map, illustrating the possibility of determining the presence of phenolic compounds through colorimetric parameters.

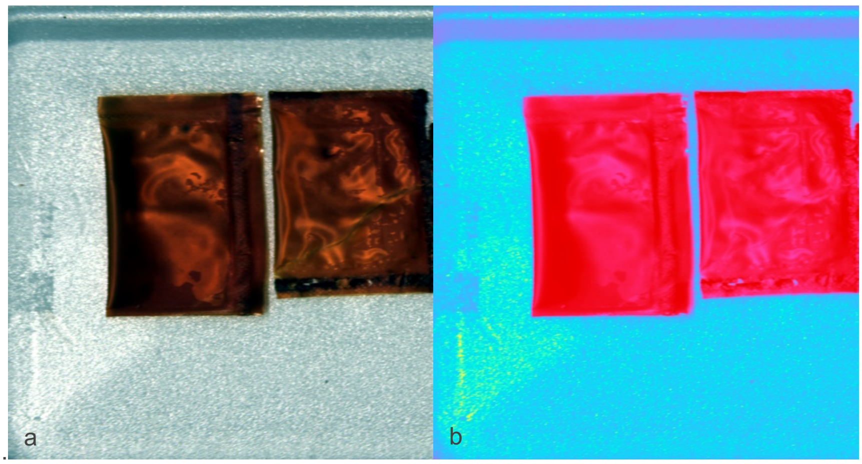

Figure 1. (a) RGB hyperspectral image of the biodegradable film without any pre-treatment; (b) Scalar-to-colormap hyperspectral image of film illustrating the presence of phenolic compounds through the color red.

The initial hypothesis suggested that the agricultural by-products used in the film formation would exhibit a significant presence of phenolic compounds, contributing to the film's functional properties. The results confirmed that the biodegradable films contained a concentration of 17,26±2,50mg $GAEcm^{-2}$ total phenolic compounds, which were unevenly distributed across the samples, as represented in Figure 2.

Figure 2. Greyscale hyperspectral image of anthocyanin reflection index in the biodegradable film.

Through detailed spectral analysis, key wavelengths where phenolic compounds exhibited strong reflectance were identified (Figure 3), facilitating their quantification. These findings have significant implications for the development of biodegradable films.The ability to accurately assess and map phenolic compounds non-destructively offers a valuable tool for optimizing film formulations and enhancing their functional properties[13]. Future research could focus on exploring additional agricultural by-products and refining the hyperspectral imaging technique to further improve the characterization and quality of biodegradable films.

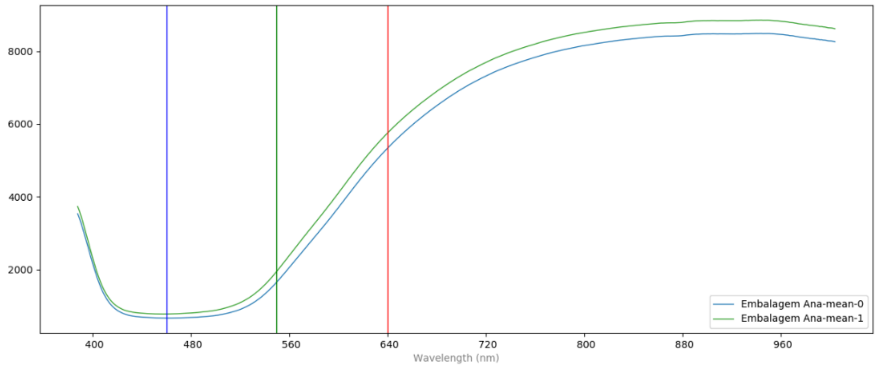

Figure 3 Graph representing the wavelengths X reflectance for the hyperspectral image of the biodegradable film in the Vis/NIR region.

4 CONCLUSION

The effectiveness of hyperspectral imaging in detecting and quantifying phenolic compounds in biodegradable films made from agricultural by-products was demonstrated using the Resonon Pika XC2 system. The system captured detailed spectral data, revealing significant concentrations of phenolic compounds unevenly distributed across the film samples. The spectral reflectance data, particularly at specific wavelengths like 430 nm, 550 nm, and 680 nm, allowed for precise identification and quantification of these compounds.

The findings confirm the initial hypothesis that the agricultural by-products used in the film formation contribute significantly to the film's functional properties through their phenolic content. The biodegradable films contained 17.26±2.50 mg GAEcm^{-2} of total phenolic compounds. This non-destructive method of assessing and mapping phenolic compounds, such as anthocyanins, offers a valuable tool for optimizing film formulations and enhancing their mechanical strength, barrier properties, and overall functionality.

Future research should aim to explore a broader range of agricultural by-products and further refine hyperspectral imaging techniques. This could involve improving spectral resolution and data processing methods to enhance the accuracy and efficiency of phenolic compound detection. Additionally, investigating the long-term stability and performance of these films in real-world applications will be crucial for their commercialization and widespread adoption.

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