
SBPMat
B-MRS
SOCIEDADE BRASILEIRA
DE PESQUISA EM MATERIAIS
SALVADOR
XXIII B-MRS Meeting 2025
September 28th to October 2nd
BRICS
Brasil 2025

# NADES-extracted hibiscus-starch cryogels as real-time food freshness sensors: a sustainable alternative

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Rising demand for fresh, high-quality food has driven the development of innovative packaging systems, especially those with intelligent features that provide real-time information on product freshness and safety [1]. This project focuses on developing pH-sensitive cryogels based on potato starch and hibiscus (Hibiscus sabdariffa L.) extract to create biodegradable, non-toxic, and cost-effective smart packaging materials. Rich in anthocyanins, hibiscus extract was used as a natural pH-sensitive dye [2]. Two extraction methods were evaluated: a conventional solvent using methanol (SOC) and a green alternative natural deep eutectic solvent (NADES), specifically choline chloride:lactic acid (1:1) with 20% (w/w) water. NADES are eco-friendly solvents with low toxicity and tunable polarity, offering improved extraction of bioactives [3]. Extracts were characterized by pH, density, polarity, total anthocyanin and phenolic content, and antioxidant capacity (ABTS assay). Cryogels were prepared by adding extracts (1, 2, 5, and 10 g/100 g starch) into potato
starch hydrogels (10 g/100 g, dry basis), then molded, freeze-dried, and stored. Colorimetric response to pH (4, 7, 10) was analyzed using CIELAB parameters (L*, a*, b*) and ΔE* via ImageJ in vapor-generating solutions. In situ performance was tested with bovine meat stored
at 4 °C for 0, 2, and 4 days. NADES extracts showed higher phenolic content and antioxidant capacity than SOC. Only cryogels with 10 g/100 g extract showed a strong colorimetric response, especially with NADES extracts. These cryogels shifted from red (acidic), rose (neutral), green (basic), with significant ΔE* values. Visible color change during meat storage confirmed their potential as smart freshness sensors. The study supports NADES as a
sustainable alternative to conventional solvents and highlights the potential of hibiscus-enriched starch cryogels for smart food packaging, with future work needed to improve sensitivity and scalability.

**Acknowledgements**
USP PUB (2918), FAPESP (2020/08727-0, 2024/10994-8, 2024/02072- 3)

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