

Nondestructive Prediction and Classification of Gel Strength in Ethanol-Treated Kudzu Starch Gels Using Near-Infrared Spectroscopy

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Abstract : Enhancing starch gel strength and stability is crucial. However, traditional gel property assessment methods are destructive, time-consuming and resource intensive. Thus, understanding ethanol treatment effects on kudzu starch gel strength and developing a rapid, nondestructive gel strength assessment method is essential for optimizing the treatment process and ensuring product quality consistency. This study investigated the effects of different ethanol concentrations on the microstructure of kudzu starch gels using a comprehensive microstructural analysis. We also developed a nondestructive method for predicting gel strength and classifying treatment levels using near-infrared (NIR) spectroscopy, and advanced data analytics. Scanning electron microscopy revealed progressive network densification and pore collapse with increasing ethanol concentration, correlating with enhanced mechanical properties. NIR spectroscopy, combined with various variable selection methods (CARS, GA, and UVE) and modeling algorithms (PLS, SVM, and ELM), was employed to develop predictive models for gel strength. The UVE-SVM model demonstrated exceptional performance, with the highest R^2 values ($R_c = 0.9786$, $R_p = 0.9688$) and lowest error rates ($RMSEC = 6.1340$, $RMSEP = 6.0283$). Pattern recognition algorithms (PCA, LDA, and KNN) successfully classified gels based on ethanol treatment levels, achieving near-perfect accuracy. This integrated approach provided a multiscale perspective on ethanol-induced starch gel modification, from molecular interactions to macroscopic properties. Our findings demonstrate the potential of NIR spectroscopy, coupled with advanced data analysis, as a powerful tool for rapid, nondestructive quality assessment in starch gel production. This study contributes significantly to the understanding of starch modification processes and opens new avenues for research and industrial applications in food science, pharmaceuticals, and biomaterials

Keywords : kudzu starch gel, near-infrared spectroscopy, gel strength prediction, support vector machine (SVM), pattern recognition algorithms, ethanol treatment

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