杨木单板/桑葚花青素高精度 pH 智能指示标签的制备及在猪肉新鲜度监测中的应用

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摘 要：随着消费者对食品安全重视程度的提高，能够迅速监测食物新鲜度的智能膜材料高速发展。pH 智能指示膜是可以根据周围环境 pH 值的改变而诱导自身颜色发生变化从而进行感知、响应的功能化材料。目前，智能膜领域的发展潜力巨大，是保障食品安全简便且先进的手段。但其存在制备过程繁琐、原料成本高、能耗大、遮光性差等问题。本研究采用杨木单板代替多糖、蛋白质等聚合物作为智能膜基材，通过碱性 H_2O_2 处理同时实现了对木材的漂白和羧基化改性，进而将羧基化单板吸附桑葚花青素，构建一种新型的 pH 智能标签（ALV）。FTIR 和 ^{13}C NMR 结果证明羧基化改性对木材的官能团和碳骨架结构没有影响。XRD 显示漂白前后单板的晶型结构始终为纤维素Ⅰ型。从 SEM 图像看出漂白前后单板表面形态相似。当 H_2O_2 和 NaOH 的浓度分别增加到 6%和 0.1 mol/L 时，单板的羧基含量和花青素吸附量分别达到 1.04 mmol/g 和 4.057 mg/g，证明羧基含量与花青素吸附量呈正相关关系。并且，ALV 具有良好的 pH 敏感性，在酸性条件下呈现紫红色，碱性条件下呈现绿色。将 ALV 放置不同湿度环境中 24 h 后，单板表面的花青素没有发生迁移，说明花青素被牢固地锚定在单板上。当 ALV 作为 pH 指示标签应用于监测猪肉新鲜度，在 TVB-N 含量达到 14.78 mg/100 g 时，接近国家标准规定的阈值（GB 2707-2016），此时 ALV 由紫红色变为灰蓝色。本研究为食品安全监测领域提供了一种安全绿色的新材料。实现了低质木材的高值化利用，并开辟了木材功能化利用的新领域。

关键词：杨木单板；H_2O_2/NaOH 处理；羧基化改性；花青素；pH 智能标签；猪肉新鲜度

Fabrication of poplar wood veneer/mulberry anthocyanins based high-accuracy pH-smart label and its application in pork freshness monitoring

Abstract: The pH-smart films are functional materials that can change their own color depending on the different pH values of the surrounding environment. Currently, there is a huge potential for development in the field of smart membranes as an easy and advanced way to protect food safety. However, it suffers from problems of complicated production, high cost, high energy consumption and low light-barrier. In this study, poplar veneer was used as an alternative to the film matrix. A strategy was realized that bleaching and carboxylation were simultaneously developed to construct a green and smart label (ALV) via alkaline H_2O_2 treatment and adsorption of mulberry anthocyanins. FTIR and ^{13}C NMR demonstrated that the carboxylation modification had no effect on the functional groups and carbon skeleton structure of the veneer. XRD showed that the crystalline structure of the veneer was always cellulose I. Besides, As seen in the SEM images, the surface morphology of the veneer was similar before and after bleaching. When the concentration of H_2O_2 and NaOH increased to 6% and 0.1 mol/L, the carboxyl content and anthocyanins adsorption amount of veneer reached 1.04 mmol/g and 4.057 mg/g, respectively.

The carboxyl content and the adsorption capacity of anthocyanins were positively correlated. ALV exhibited good pH-sensitivity, which appeared purplish-red in acidic conditions and green in alkaline conditions. Moreover, there was no migration of anthocyanins from the veneer surface when ALV was placed for 24 h in different humidity environments (33%, 53%, 75% RH). It indicated that the anthocyanins were firmly anchored on the veneer. The color of ALV changed from purplish red to dark blue when the TVB-N of pork reached 14.78 mg/100 g, which was close to the threshold value of GB 2707-2016. This study provides a new material that can supervise the freshness of food in a safe and green way. It achieves a high-value conversion and utilization of low-quality wood, opening up a new field of wood utilization.

Key words: poplar veneer; H_2O_2/NaOH treatment; carboxylation; anthocyanins; intelligent label; pork freshness.