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Innovative Responsive Delivery System for Improving Safety and Shelf Life of Minimally Processed Packaged Fruit Salad

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Abstract

Recent studies on active antimicrobial packaging have focused on controlling the release of natural volatile compounds to inhibit microbial growth in food. A novel approach involves using reversible covalent bonds to anchor and release the active compound as needed in response to one or more external stimuli. The aim of this study was to design a delivery system based on chitosan films with acid responsive release of antimicrobial trans-2-hexenal to extend the shelf life of fresh fruit salad. Responsive chitosan-based films were developed by covalently anchoring trans-2-hexenal to preformed films through the formation of imine bonds. The resulting aldehyde-functionalized films were characterized to confirm bond formation and their reversibility by means of hydrolysis under mild acidic conditions. Antimicrobial activity was first evaluated *in vitro* against *Salmonella enterica*, *Escherichia coli*, *Listeria innocua* and *Botrytis cinerea*. The films were incorporated into double-bottom polylactic acid (PLA) containers and evaluated using a fresh fruit salad consisting of cubes of melon, pineapple, and grapes. The samples were stored at 4 °C for 12 days and the microbiological load and freshness parameters were monitored during storage. The salad was also inoculated with the pathogenic bacteria mentioned above and the microbiological efficacy of the active packaging was evaluated. In addition, the trans-2-hexenal content of the fruit salad was analysed on days 3, 6, 9 and 12 of storage. The films showed *in vitro* microbicidal activity, as fruit exudates triggering imine bond hydrolysis and aldehyde release. The active packaging system effectively maintained microbial loads within acceptable limits, showing notable reductions compared to control samples. After 12 days of storage, mould, yeast and mesophilic microorganisms reached 5.2 log CFU/g in the control fruit, while values of 2.9 log CFU/g were observed in the fruit packaged with the active system, highlighting its effectiveness in preserving fruit quality. The system also reduced inoculated *Salmonella enterica*, *Listeria innocua* and *Escherichia coli*. On day 12, trans-2-hexenal concentrations were 3.1 ± 0.4 µg/g and 2.0 ± 0.4 µg/g when 0.5 g and 0.25 g of active film were used, respectively. These novel packaging systems effectively prolong the shelf life of minimally processed fruit salads, which contributes to minimize food waste in the retail sector and consumers home.

Keywords: Chitosan, trans-2-hexenal, antimicrobial active packaging, microbial load, fruit salad

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