THE IMPACT OF SMART PACKAGING ON FOOD WASTE REDUCTION AND SHELF-LIFE EXTENSION: A QUANTITATIVE META-ANALYSIS

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Abstract

This paper quantitatively evaluates the impact of smart packaging on shelf-life extension and food waste reduction. The working method involved a meta-analysis of literature data regarding the performance of time-temperature indicators, freshness sensors, and gas indicators. Data from experimental studies were aggregated to establish correlations between sensor color changes (ΔE) and microbiological spoilage thresholds. The synthesized results demonstrate that dynamic monitoring significantly increases product shelf life compared to conventional packaging relying on static expiration dates. The practical application lies in supporting the transition to a circular economy through food safety digitization. The originality of this study lies in the integrated quantification of sensor efficiency as a direct alternative to static labeling. It is concluded that smart packaging optimizes the supply chain and effectively reduces the premature disposal of safe food.

Key words: *food waste, freshness sensors, meta-analysis, smart packaging, time-temperature indicators*