

## 第 28 回農学部賞 受賞者

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# 第28回生物資源環境科学府賞 受賞者

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(博士後期課程) 環境農学専攻 農産食料流通工学分野  
「Sustainable Agro-Waste Valorization: Carbon Quantum Dot-Reinforced Biopolymer Nanocomposites for Active Food Packaging and Computational Drying Modeling on Off-Grade Produce (農業廃棄物の高付加価値化：アクティブ包装向けカーボンクォンタムドット強化バイオポリマーナノコンポジットと規格外農産物の乾燥解析モデル)」

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( 農業廃棄物の高付加価値化：アクティブ包装向けカーボンクオンタムドット強化バイオポリマーナノコンポジットと規格外農産物の乾燥解析モデル)

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### Thesis Summary 論文内容の要旨

Sustainable valorization of agro-industrial waste and preservation of the off-grade foods represent a critical research frontier in addressing the growing global challenges of food waste, environmental pollution, and the demand for eco-friendly food preservation solutions. This thesis presents a comprehensive investigation centered on the synthesis of carbon quantum dots from food waste materials, their incorporation into the fabrication of biopolymer nanocomposite films for active food packaging, and the prediction and optimization of fruit drying quality through computational frameworks for off-season utilization, collectively advancing the sustainable utilization of agro-waste materials across three interconnected studies.

In the first study, leftover pumpkin peels were used to green-synthesize carbon quantum dots (CQDs), which were then added to nanocomposite films based on carboxymethyl cellulose/gelatin (CMC/Gel). The synthesized CQDs demonstrated excellent antioxidant and UV-blocking properties, indicating their potential as functional active agents for food packaging applications. Strong compatibility between CQDs and the CMC/gelatin polymer matrix, mediated by intermolecular bonding, was confirmed by SEM and AFM. During cherry tomato preservation, the optimized CMC/Gel/PP\_CQDs 3% formulation showed exceptional water vapor permeability, water contact angle performance, and efficient food pathogen suppression, underscoring its great potential for useful active food packaging applications.

The second study methodically examined the combined effects of nitrogen doping and hydrothermal synthesis temperature on the structural, optical, and functional characteristics of carbon dots made from leftover orange peel, as well as how these factors affected the functionality of chitosan/gelatin-based biodegradable packaging films. It was found that nitrogen inclusion altered fluorescence properties and increased the zeta potential, whereas the synthesis

temperature-controlled particle size independently of nitrogen doping. Compared with unpackaged controls, the Chitosan/Gelatin/Nitrogen doped carbon dots synthesized at 180°C (Chit/Gel\_N-CD-180) formulation demonstrated the best composition, with superior barrier properties, enhanced antioxidant and antibacterial activities, and efficient preservation of fresh cherry tomatoes, thereby extending shelf life. This indicates that nitrogen doping and synthesis temperature are critical factors influencing the performance of the composite film.

In the third study, a macroscale computer model was developed to simulate volumetric heating and quality dynamics during the convective drying of food items by combining heat and mass transfer with a geometric deformation model. The model, which was based on the equations of Fourier and Fick, correctly predicted temperature and moisture profiles for drying temperatures between 50 and 70°C. The simulated findings showed good agreement with the experimental data. A useful computational tool for determining the best drying techniques and reducing quality losses during food processing, the model was subsequently expanded to predict the kinetics of quality deterioration, including color, phenolic content, and antioxidant activity.

In conclusion, this thesis demonstrates that carbon quantum dots derived from agricultural waste are sustainable and effective functional reinforcements for biopolymer-based active packaging films, and that the developed computational drying framework provides a powerful platform for optimizing food processing. When taken together, these discoveries provide a significant and coherent scientific contribution to eco-friendly food packaging, computationally guided food drying, and sustainable agro-waste valorization. These technologies have great potential to advance toward wider industrial and practical applications.