AI and Kinetic Modeling of Thermal Death in Yellow Mealworm (*Tenebrio molitor*) Larvae

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***Abstract*:**

Insect farming for food and feed has grown rapidly; however, current processing conditions neither guarantee nor clearly describe humane practices during slaughter. Our study developed statistics-based kinetic and data-driven artificial intelligence (AI) models to describe thermal death of yellow mealworm (YML) subjected to hot air (HA) and hot water (HW) treatments. For HA treatments, AI boosting models (CatBoost, XGBoost, and LightGBM) were evaluated to assess how larval characteristics (mass, length, width, moisture content, and area-to-volume ratio) influence death time. For HW treatments, statistical (Normal and Weibull distributions) and kinetic (Sigmoidal) models were applied to predict larval survival probability under isothermal conditions (primary models), which were subsequently correlated with processing temperatures (secondary models) to estimate death kinetics under variable thermal conditions. Among the AI models, LightGBM showed the best performance (RMSE = 3.592, MAE = 2.581, R^2 = 0.924), with air temperature identified as the most influential feature. Sigmoidal models adequately described both Normal and Weibull survival distributions, although Normal distribution–based models showed more stable behavior in secondary modelling. Overall, this integrated framework provides a quantitative basis for selecting thermal processing conditions that ensure effective slaughter of YML while promoting welfare-oriented practices.

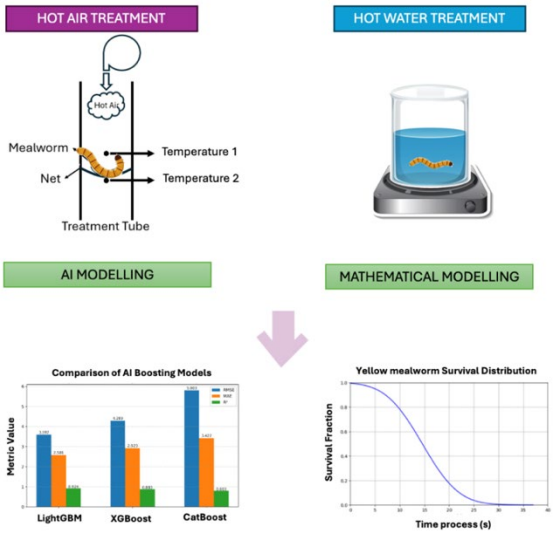

Figure. Overview of experimental and modelling workflow

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