Abstract:

Grading is an essential process during packing to remove defected apples (Malus Domestica Borkh.), returning benefits to apple industry and consumers. As an alternative to other grading techniques (e.g., grading by hand, CCD camera, near-infrared (NIR) reflection or transmission), thermal imaging also detects bruises in apples. The evidence of bruise in thermal images during transient heating indicated that thermal properties were different between bruised and sound tissues, mainly due to thermal diffusivity ($\alpha$) differences. This article discusses the measurement of the $\alpha$ components and the validation of thermal imaging bruise detection using finite element (FE) modelling and the measured $\alpha$ components. Thermal conductivity (k), specific heat (Cp) and density ($\rho$) which are components of $\alpha$ in the relationship $\alpha=k/(\rho\bullet Cp)$, were measured individually for bruised and sound tissues using the modified Fitch's method, differential scanning calorimetry, and density=mass/volume, respectively. Results revealed that k was approximately 20% higher and $\rho$ was approximately 5% higher in bruised than in sound tissues, while Cp was unchanged. The k-value dominates changes in $\alpha$, resulting in $\alpha$ of 14.3% higher in bruised than in sound tissues. Applying $\alpha$ to the simulation accordingly, the FE model showed that surface temperature of bruises (with greater $\alpha$) warmed up more slowly than that of sound tissues (with smaller $\alpha$) during heating scenarios, comparable to the findings of bruise detection by thermal imaging. Hence, a bruise may serve as a thermal window to transfer heat to or from the interior of apples. The FE model not only illustrated a linkage between thermal properties and heat transfer of bruised apples but also provided flexibility for the design of thermal image bruise detection system.