Heat Transfer Modeling of Innovative Infrared Heating for Pear Peeling

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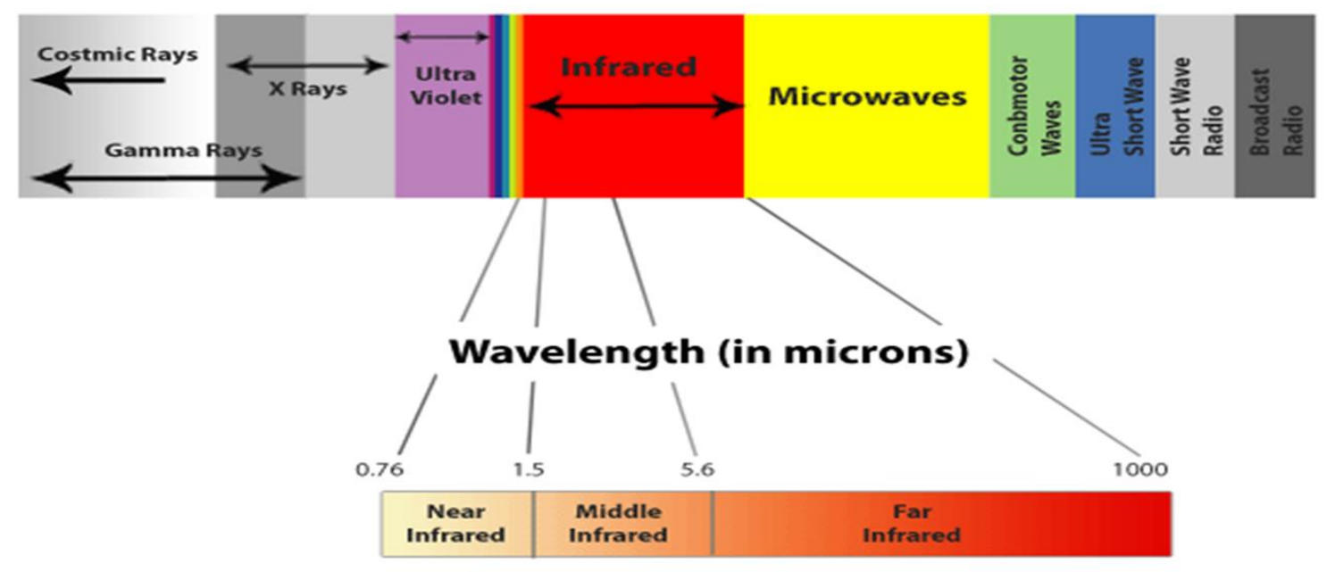
Abstract

Infrared (IR) dry-peeling of pear involves comprehensive heat transfer phenomena including radiative and convective heat transfer on the surface, as well as conduction in the fruit. To understand the phenomena and evaluate the heating performance, there is a significant need to simulate pear temperature distribution profile during the heating process. A three-dimensional cylindrical symmetric heat transfer model was developed for Bartlett pear under an electric IR heating system. The system comprised of two ceramic IR emitters and a rotation rod. Model was validated with measured surface temperature on the bell equator. The surface temperature distribution indicated that the top and bottom parts of pears had lower temperature. It took only 56 s to heat the skin layer to 110°C while the inner part (flesh) remained around ambient temperature. The quality of inner part was maintained due to high heat absorbance at the surface during IR heating.

Background

IR radiation is the electromagnetic radiation form of energy. Advantages of IR heating include high heat delivery capability, rapid surface heating, reduced processing time and energy consumption, and improved product quality and safety. In our previous study, a pilot-scale IR peeling system developed for the Bartlett pear demonstrated high peeling yield (94.44%) and limited peeling losses (9.89% to 13.80%) without water use and wastewater generation. Computational simulation of IR heating, however, in the pear peeling process has not yet been explored. A mathematical heat transfer model is useful for understanding the comprehensive thermal energy delivery during the peeling process and provide a proper evaluation of the heating performance.



Electromagnetic spectrum

IR peeled pears

Objectives

- **To develop a mathematical heat transfer model for temperature distribution profile during IR heating of pear.**
- **To validate the model with measured surface temperature.**

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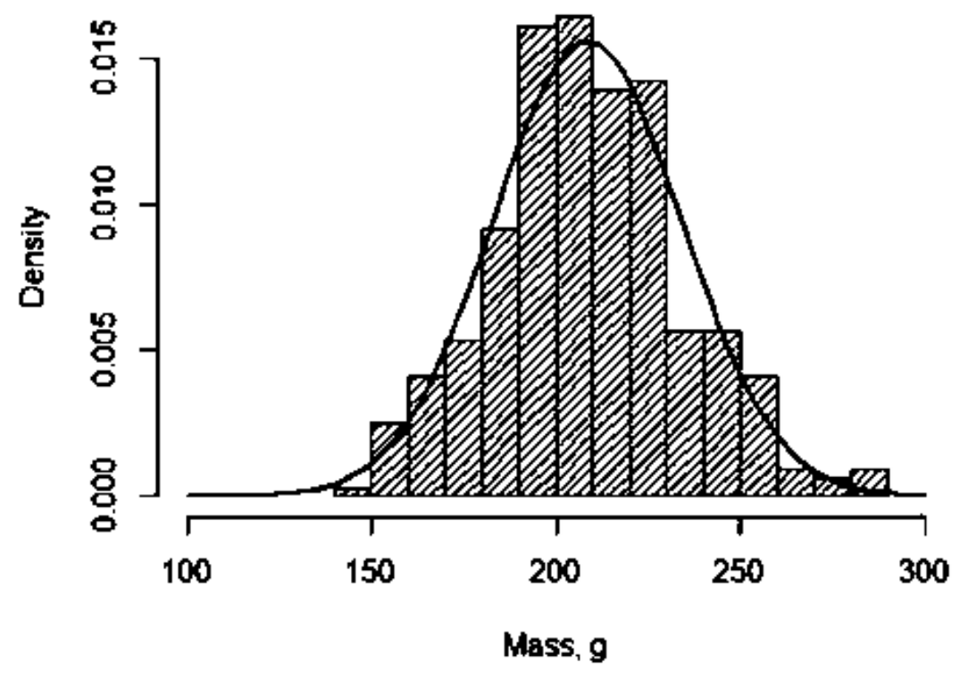
Materials and Methods

Samples

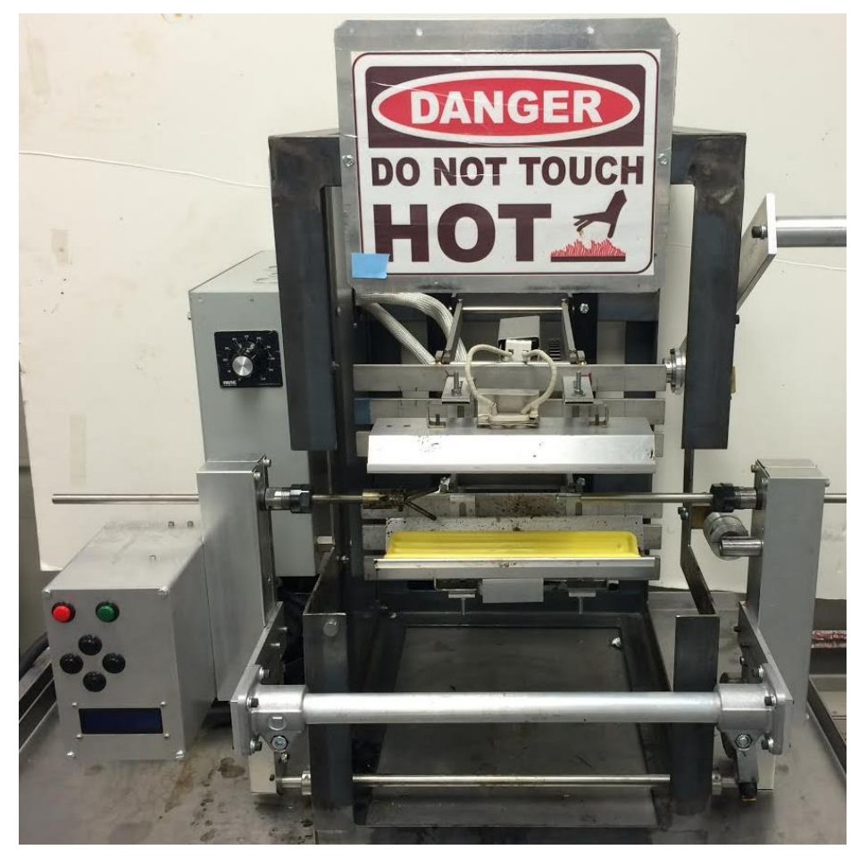
Based on the histogram of sample mass, medium Bartlett pears with size *90* (around 222 g) were selected for the tests. The average length, bell and neck diameter of selected pears were 83.98, 73.38, and 38.03 mm, respectively.



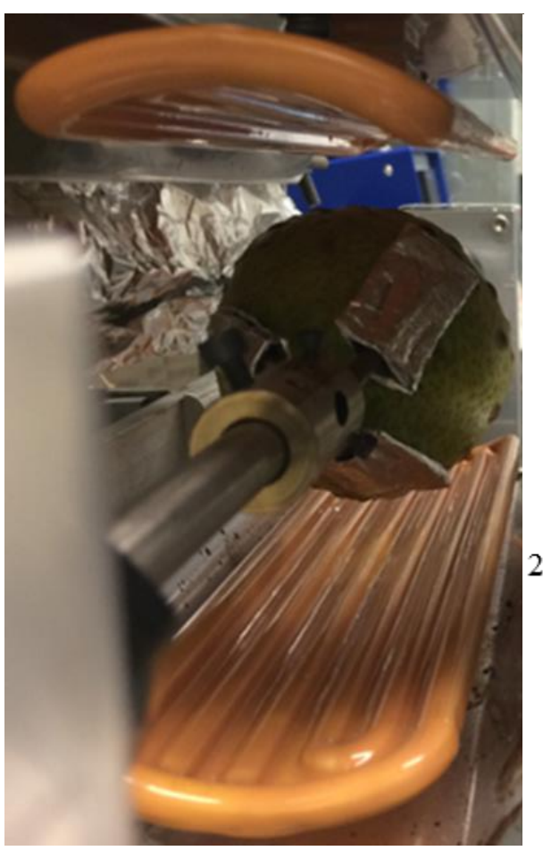
Pear weight distribution

IR heating system

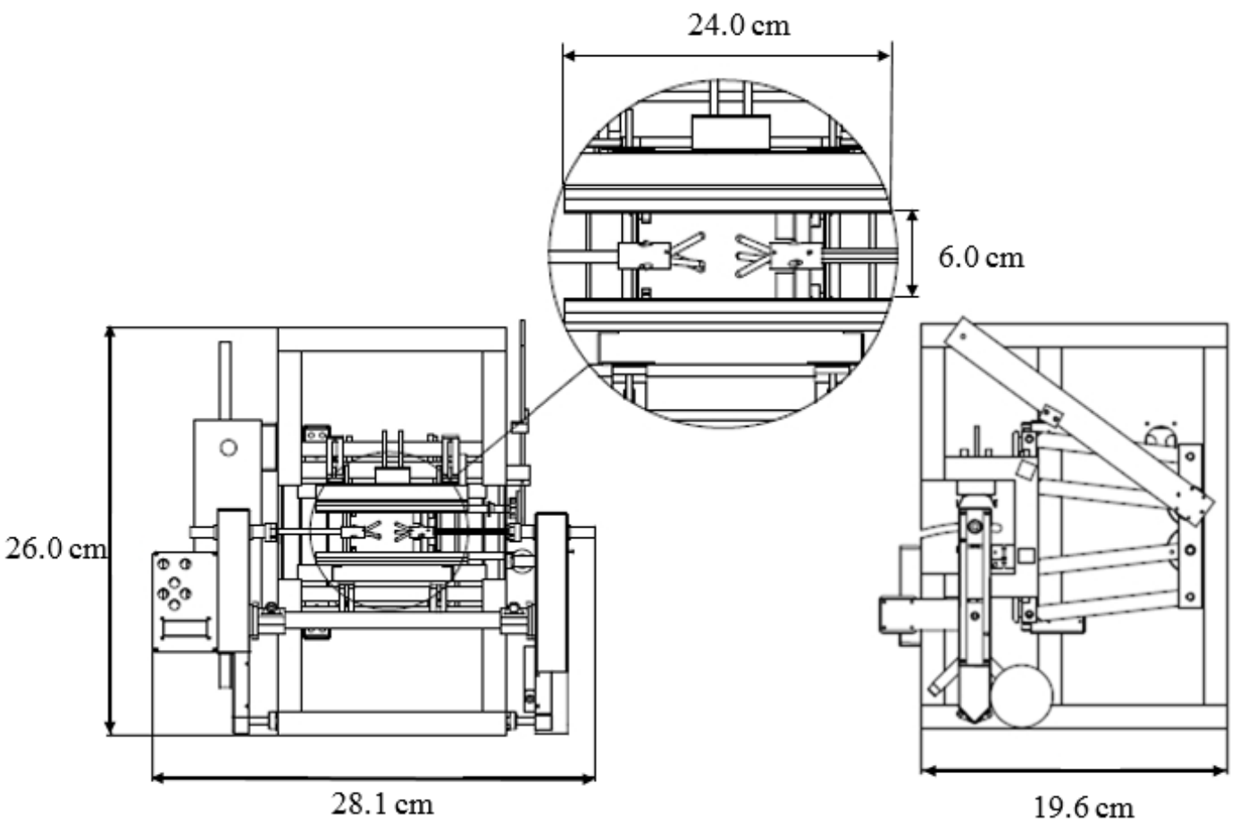
A ceramic IR heating system was used to conduct the heating tests and build the heat transfer model. The heating system consists of two ceramic infrared emitters (full trough emitter, Ceramicx Ireland Ltd, 1000 W, 60*245 mm surface area, 100 mm gap, 0.93 emissivity) with surface temperature of 601 ± 25°C and a rotation rod (5 rpm).



IR heating system



Pear heating layout



System schematic diagram and dimension

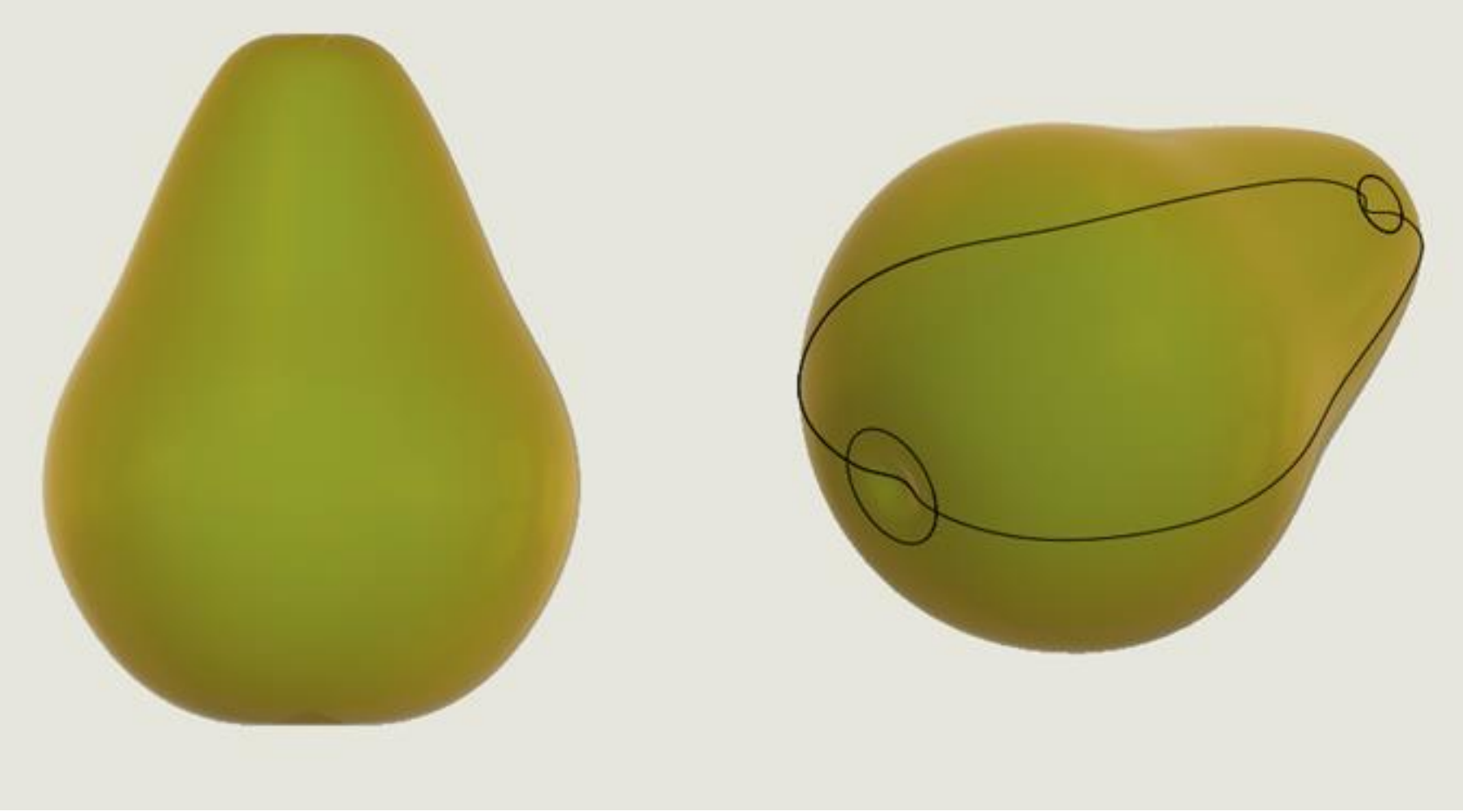
Major modeling assumptions

Moisture losses is negligible (around 0.5%)
Radiation energy is absorbed at the exact surface
The system is cylindrical symmetric
Thermos-physical properties of system is temperature-dependent

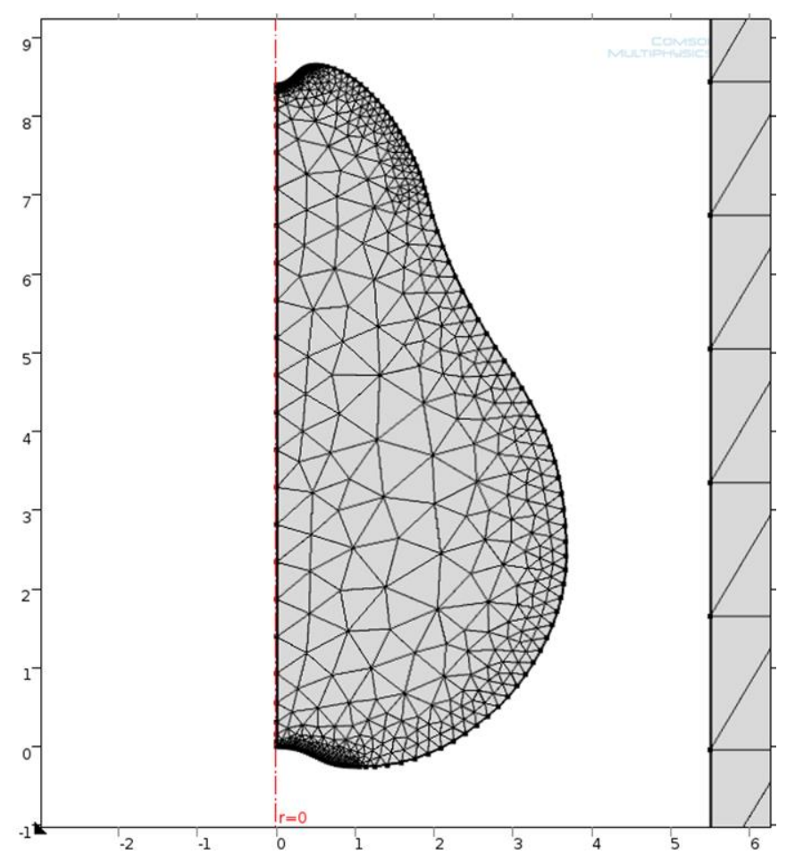
Geometric model and meshing

Three-dimensional geometric model of pear was constructed using the average length, bell diameter, and neck diameter measured above. The geometric model was described by the Bezier Curve.

A mesh consisting of tetrahedral volume elements was generated for the simulation. "Extremely fine" meshes were created on the pear surface, while "Coarse" meshes were applied in the center of pear.



Geometric model



Mesh details on the geometric domain

Governing equation

$$\rho c_p \frac{\partial T}{\partial t} = \frac{k_r}{r}\frac{\partial}{\partial r} r \frac{\partial T}{\partial r} + k_z \frac{\partial^2 T}{\partial z^2} + \nabla P_0 exp(-2\alpha d)$$

Boundary conditions and initial condition

$-\vec{n} \cdot (-k\nabla T) = \overline{h}(T_{amb} - T_{sur})$ **On the pear surface**

$-\vec{n} \cdot (k\nabla T) = 0$ **At the center of the pear**

$\mathrm{T} = T_{ini}\ at\ t = 0$

Materials and Methods (Continued)

Modeling and validation

Three-dimensional cylindrical symmetric heat transfer model was constructed using COMSOL software. The temperature profiles were measured using Infrared camera (FLIR E40) on the bell equator surface.

Results and Discussion

The experimental results were not significantly different from simulation results (Fig. 1). The surface temperature distribution was not uniform along the contour (Fig. 2). The top and bottom parts of pear had much lower temperature.

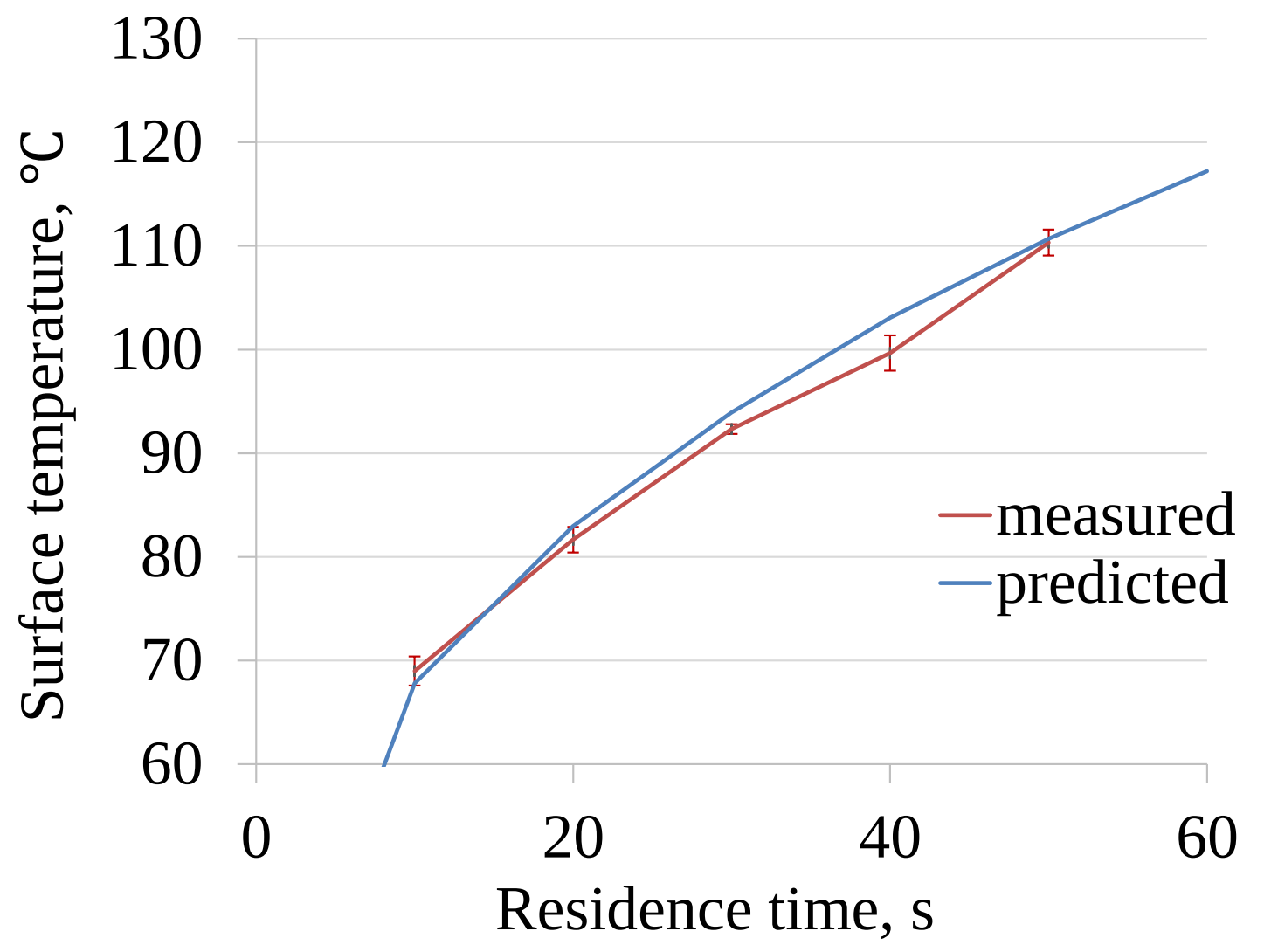


Fig. 1 Surface temperature validation

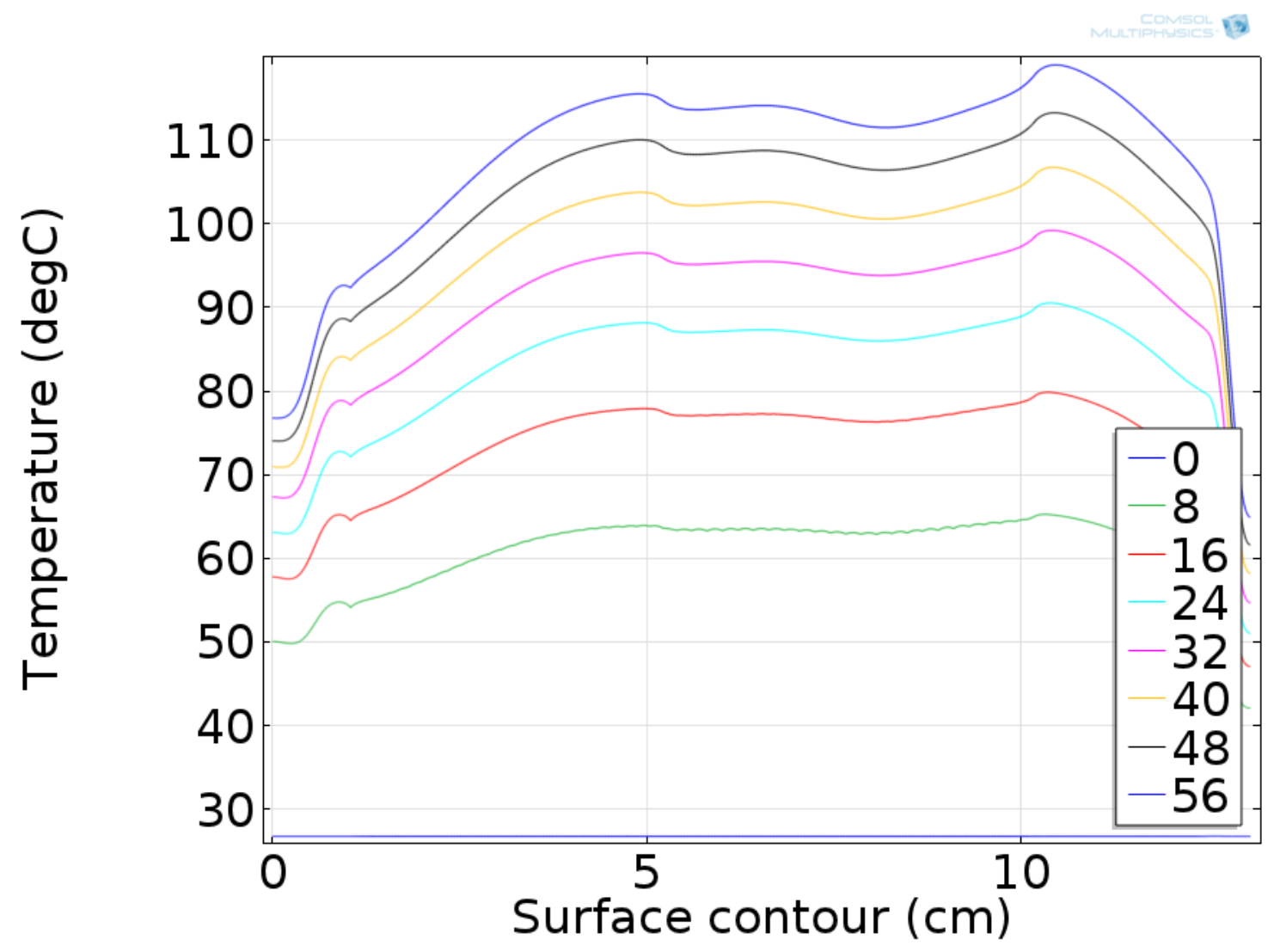


Fig. 2 Surface temperature at different heating time

The temperature distribution showed that the major inner area remained around ambient temperature (25°C), while the surface layer was heated up to 110°C after 56 s of IR heating (Fig. 3). The large temperature gradient indicated IR heating could achieve a rapid surface heating while preserving the quality of inner part (flesh).

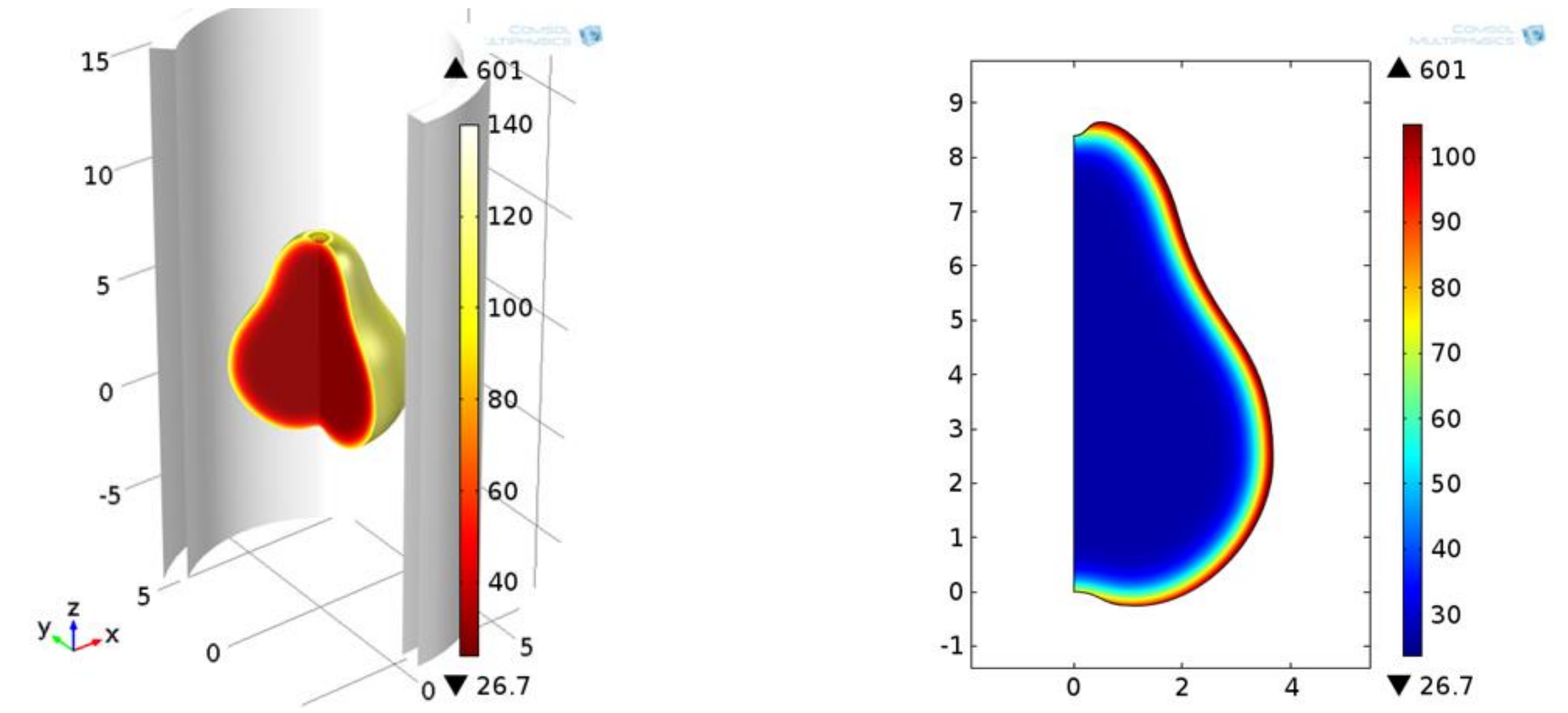


Fig. 3 Temperature distribution at 56 s: **A** three-dimensional temperature distribution; **B** two-dimensional cross section temperature distribution

Conclusion

The mathematical model demonstrated good predictive capability of temperature profiles of Bartlett pear during IR heating. IR heating can provide rapid energy delivery to the fruit surface without causing severe thermal damage to the flesh.

Acknowledgment

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