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Research Paper

Prediction of surface temperature of figs during infrared heating and its effect on the quality

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Fresh figs have a short shelf-life due to a fast softening rate and fungal spoilage. Infrared heating treatment as a surface decontamination technique could be applied to the ostiole, where most mould growth is observed. However, the quality of fresh fruits could be degraded if the heat treatment is too severe. The objective of this study is to find the optimal trade-off between a fungal decay reduction and a fruit quality. Figs were treated with infrared heating until they reached maximum temperatures of 50 °C, 60 °C and 70 °C. A heat transfer model was employed to calculate the treatment time required for each treatment group. Quality assessment was performed after six days of storage at 7 °C. At the lowest heating treatment group of 50 °C, a suppression of fungal development was achieved without a significant heat injury.

1. Introduction

Figs are climacteric fruits but harvested when fully ripe for optimum flavour (Tsantili, 1990). At this stage, they are soft and easily bruised. Figs also have a natural opening ostiole, which is undesirable as the exposed flesh provides conditions for mould growth, making it susceptible to fungal decay. The ostiole starts to open as figs mature and its width was reported as 1.0–9.4 mm (Polat & Özkaya, 2005). Fresh figs have short shelf-life due to fast softening rate and development of mould growth especially on the area around the ostiole. Although there have been many studies on decontamination techniques for figs, most have focused on eliminating aflatoxin in dried figs (Öztekin, Zorlugenç, & Zorlugenç, 2006; Zorlugenç, Kiroglu Zorlugenç, Öztekin, & Evliya, 2008). For fresh fruits, conventional washing with water is not suitable as free water may remain within the ostiole, inducing the germination of fungal spores. Karabulut, Ilhan, Arslan, and Vardar (2009) fumigated figs with chlorine dioxide and found a significant reduction of total microorganisms. However, due to concerns over the effect of chemical residue on human health, other chemical-free methods are preferred.

Infrared (IR) heating is a contactless and chemical-free method that has been used for disinfection. It has many benefits such as efficient heat transfer, reduced time and energy, cool ambient surrounding air, high controllability and

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Nomenclature

C_{Pa}	air specific heat capacity [J kg^{-1} K^{-1}]
C_{Ps}	specific heat capacity of fig [J kg^{-1} K^{-1}]
F	prediction value
$\mathbf{g}$	gravity vector [m s^{-2}]
h	local surface heat transfer coefficient [W m^{-2} K^{-1}]
k_a	air thermal conductivity [W m^{-1} K^{-1}]
k_s	thermal conductivity of fig [W m^{-1} K^{-1}]
O	measurement value
$\mathbf{n}$	outward normal to the fig surface
N	number of pairs of data
p	pressure [Pa]
q_{rad}	radiation flux
RMSE	root mean square error
t	time [s]
T_a	air temperature [K]
T_s	the temperature of fig [K]
$\mathbf{u}$	air velocity vector [m s^{-1}]
ρ_a	density of air [kg m^{-3}]
ρ_s	density of fig [kg m^{-3}]
$(\rho_a - \rho_{a,ref})$	density difference of air [kg m^{-3}]

safety, and more uniform heating than conventional oven as surface irregularities have smaller effect on the heat transfer rate (Krishnamurthy, Khurana, Soojin, Irudayaraj, & Demirci, 2008; Sakai & Hanzawa, 1994). Because of its rapid heating rate, optimum treatment conditions are needed to prevent the overheating of the fruits. IR heating can be used to inactivate microorganisms in both liquid and solid foods as investigated in the previous studies (Hamanaka, Uchino, Wenzhong, Tanaka, & Aramaki, 2003; Jun & Irudayaraj, 2003). Heat treatment may also melt the wax platelets which encapsulate and inactivate the microbial spores (Schirra, D'hallewin, Ben-Yehoshua, & Fallik, 2000). Hashimoto, Igarashi and Shimizu (1992) also found that far-infrared irradiation is more effective at pasteurisation of bacteria on the agar plate than hot-air heating. Hamanaka et al. (2011) introduced a combination of IR heating and ultraviolet (UV) irradiation on fresh figs. However, there had been a few studies on the optimisation of IR heating conditions on fresh fruits.

The optimisation of the IR heating process for surface decontamination should be conducted in order to reduce the postharvest decay without affecting the fruit quality. In this research, the ostiole side of the fig fruits was exposed to IR heating to observe the decay incidence. The fruit quality associated with maximum surface temperature was also investigated after storage. In addition, a mathematical model for heat transfer was developed to predict temperature change on the fig surface. This can be done by simulating the actual IR heating using 3D finite volume analysis. The results of the simulation can be validated with experimental data.

2. Materials and method

2.1. Modelling of temperature on the surface of figs

2.1.1. Geometry and mesh

The three-dimension model of a fig (Fig. 1A) was constructed based on an actual fruit (Fig. 1B). The coordinates of the points along the fig surface were obtained using an image editing software. Calibration was performed by comparing with the pixel resolution of objects of known length. In the software ANSYS Workbench version 12.1 (ANSYS Inc., PA, USA), the geometry of the set-up consisting of a lamp, a reflector and a fig was constructed as shown in Fig. 2. Due to its symmetrical nature of the problem, to reduce calculation time only a quarter of the volume was used. A mesh with 218,354 elements was created with refinement near boundary layers as shown in Fig. 3.

2.1.2. Radiation model

The Monte Carlo ray-tracing technique was used to simulate the radiative heat transfer. The radiative heat transfer is calculated by randomly releasing a statistically large number of energy bundles and tracking their progress from their emission points through the medium. The modelled random events were surface absorption and reflection, which were input into the convection–diffusion heat transfer model to be

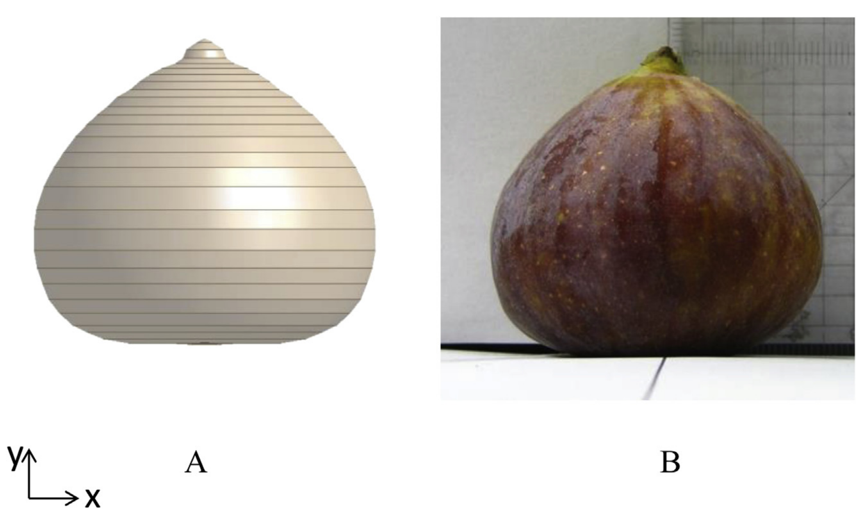

Fig. 1 – Constructed fig geometry (A) and photographed fig (B).