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Thermal imaging during infrared final cooking of semi-processed cylindrical meat product

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HIGHLIGHTS

- Infrared cooking was applied as final cooking for semi-cooked meatballs.
- Temperature homogeneity is a critical factor in control engineering.
- Thermal imaging served more convenient temperature measurement than contact one.
- The hottest and coldest points of samples were determined clearly from thermal images.

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ABSTRACT

The temperature measurements during the infrared cooking of the semi-cooked cylindrical minced beef product (*koefte*) were taken by both contact (thermocouples) and non-contact (thermal imaging) techniques. The meat product was semi-cooked till its core temperature reached up to 75 °C by ohmic heating applied at 15.26 V/cm voltage gradient. Then, infrared cooking was applied as a final cooking method at different combinations of heat fluxes (3.7, 5.7 and 8.5 kW/m^2), applied distances (10.5, 13.5 and 16.5 cm) and applied durations (4, 8 and 12 min). The average surface temperature increased as the heat flux and the applied duration increased but the applied distance decreased. The temperature distribution of the surface during infrared cooking was determined successfully by non-contact measurements. The temperature homogeneity varied between 0.77 and 0.86. The process condition of 8.5 kW/m^2 for 8 min resulted in core temperature greater than 75 °C, which was essential for safe production of ready-to-eat (RTE) meat products. Thermal imaging was much more convenient method for minimizing the point measurement mistakes and determining temperature distribution images more clear and visual.

1. Introduction

Thermal processing is a requirement for the ready-to-eat meat products and brings about desirable changes in color, texture, structure and sensory properties. Temperature is an important factor affecting microbial growth in meat products, and hence it is the most controlled and monitored parameter for food safety in the meat industry [1,2]. The temperature and the heating time during thermal processing are specified to ensure the safety of the meat product.

Thermal imaging is a non-destructive and non-contact temperature sensing technique. It can be applied to food samples noninvasively [3,4]. The principle of thermal imaging is based on the radiation emitted from an object, and thermal imaging equipment produces a pseudo image of the thermal distribution of the object. Hence, the non-contact and the high resolution temperature measurement is possible [5,6]. The advantages of thermal imaging method compared to other temperature measuring methods are the prevention of the contamination risks by non-contact measuring, the possibility of the instant result of temperature for a specific point and the temperature distribution, absence of the harmful radiation during process, being easy to use and the requirement of the minimal instrumentation [4,7,8]. Fuller et al. [9] indicated that thermal imaging is much more reliable and an alternative method for studying the freezing and ice nucleation of plant tissues than contacted measurements by thermocouples. It could avoid mounting a contact measuring unit to the product.

Thermal imaging technique is used for applications in agriculture such as the determination of plant physiological state, irrigation scheduling, yield forecasting, maturity evaluation of fruits, detection of bruises in fruits, and detection of spoilage by microbial

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activity and there is limited application of this technology in grain storage [6]. Furthermore, it is used in microbiological growth detection, spoilage detection of meat products and temperature distribution detection within the processing equipments. Another novel use of thermal imaging was to monitor the surface temperature in steam systems for determining the heat transferred and the heating uniformity in the treated object [10]. On the other hand, the knowledge on the alternative use of thermal imaging during cooking of meat products in the literature is limited [3,11,12]. Since contact temperature measurements during the cooking of meat products can be taken by thermocouples, the measurement from different points of meat product could affect the homogeneity of the heating process and is not practical during cooking process in the industrial scale. The non-contact temperature measurement is preferable to contact temperature measurement by reason of difficulties about inserting and immobilizing thermocouples to the various points of sample during processes.

In recent years, the alternative heating technologies, such as ohmic, infrared, radio frequency heating methods, have been used to increase the temperature homogeneity in the food products. Ohmic heating involves the application of the electricity to food material, resulting in volumetric heat generation [13,14]. The use of ohmic cooking in meat products offers a number of advantages such as faster cooking, less power consumption and safer product [14,15]. Besides, ohmic cooking is not a sufficient method to obtain an acceptable vision and color of a cooked meat. As mentioned in the previous paper [16], the overall visual acceptance of the cylindrical meat product cooked ohmically (15.26 V/cm, up to the core temperature of 75 °C) was "good" but lower than that of meat product cooked conventionally. In addition, they concluded that this condition was not effective in the elimination of *L. monocytogenes*. They mentioned that this technique need a supplementary process accomplishing cooking properties of meat products.

Infrared cooking is based on the penetration of electromagnetic waves to the food material. The absorbed infrared waves (0.78–1000 μm) could cause electromagnetic vibrations and result in temperature increase within the food material. The penetration capacity of infrared waves limits the whole cooking of food material. Thus, infrared cooking procedure is much more convenient for surface cooking or thin shaped food samples.

The objective of this study was to investigate the effects of different combinations of heat fluxes, distances and durations on temperature distribution of cylindrical meat product during infrared cooking. The temperature measurements were taken by contact and non-contact techniques during the infrared cooking applied at different conditions (different combinations of heat fluxes, distances and durations) as final cooking method for semi-cooked cylindrical meat product. It was aimed to determine the process conditions (combinations of heat flux, distance and time) resulted in core temperature greater than 75 °C, which was essential for elimination of pathogenic bacteria and production of ready-to-eat meat products. Another objective of this study was to investigate the laboratory usage of thermal imaging if it was an alternative temperature measurement technique during infrared cooking of meat products.

2. Material and methods

2.1. Material

The round of beef was procured from a local processor (Burdur Gucbirligi Meat Facility S.A.). Meat samples, arrived in vacuum packages via cold chain (−18 °C), were cut into 200–300 g pieces and frozen in low density polyethylene (LDPE) bags and stored at −18 °C until used. Thawed meat samples (at 4 °C for one night) were ground through a 3 mm plate grinder (Tefal, Turkey), and mixed with the ingredients. Meat product was prepared according to the following recipe: meat (96% w/w), onion powder (1% w/w), salt (0.5% w/w), sodium carbonate (0.5% w/w) and distilled water (2% v/w). Mixture was kneaded for 15 min by hand, to obtain homogeneous dough. The prepared dough was stored in a refrigerator (at 4 °C) for an hour and then shaped into cylinder meat product having 2.5 ± 0.2 cm diameter and 5.0 ± 0.2 cm length by using a cylindrical block.

The moisture and ash contents were determined by using the method given in [17]. The crude protein and the crude fat contents were analyzed according to the methods given in [18,19], respectively. The composition of meat dough was determined and standardized for all cooking processes.

The processing of meat product was carried out at ambient temperature of 22.90 ± 2.88 °C.

2.2. Ohmic-infrared cooking system

In this study, the pre-cooking method before infrared treatment was ohmic cooking. The experiments were conducted in specifically designed custom-made continuous belt type ohmic cooking system described in detail in the previous study [20]. The sample was placed at the inlet of the continuous type cooking unit and sandwiched between the electrodes with compression. After the system was sealed, belt was rotated at the speed of 0.25 cm/s, and then cooking was started. The cylindrical meat product was semi-cooked until its core temperature reached up to 75 °C by applying optimum ohmic semi-cooking condition determined in the previous paper [20].

Ohmically pre-cooked meat products were directly transferred to the infrared cooking unit which was already combined to the ohmic cooking unit (Fig. 1). The detailed information about the infrared cooking procedure had been given in the previous study of the project team [21]. The infrared cooking unit was designed to involve a specially rotating belt with motor for controlling speed, power supply controlled with closed-circuit microprocessor unit and heating cabinet. Microprocessor controlled closed-loop power control system was specially designed to measure the power of infrared system, to control the requisite current and the voltage. The infrared heating cabinet consisted of specially polished reflective stainless steel inside walls, infrared heating units (4 μm wavelength) and temperature measurement units.

Infrared cooking parameters were three different heat fluxes (3.7, 5.7 and 8.5 kW/m^2), three different applied distances (distance between infrared unit and surface of meat product; 10.5, 13.5 and 16.5 cm) and three different durations (4, 8 and 12 min). Full factorial experimental design with 3 parameters was used. 27 different infrared cooking conditions were conducted in triplicate.

2.3. Contact temperature measurements

Teflon coated T-type Kapton-insulated thermocouples (Cole Parmer, USA) and semi-conductive temperature sensors (LM35, Omega, USA) were used to measure temperatures at different points of meat product (core and surface) and the surfaces of the infrared system (Fig. 2). The microprocessor system was used to monitor the temperatures and to transmit this information simultaneously to the microcomputer at constant time intervals (1 s).

2.4. Non-contact temperature measurements

Non-contact temperature measurements were conducted by using thermal camera (Testo 880-3, Germany). The measurements were taken at four stages of process (Table 1). After infrared