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MODELING OF COOKING STRIP LOIN AND OUTSIDE ROUND STEAKS IN A FORCED-AIR CONVECTION OVEN

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Summary

We used a forced-air convection oven to cook steaks from two muscles; strip loin (longissimus lumborum) and outside round (biceps femoris). We used a mathematical model to predict cooking time and temperature profiles for each steak. No differences (P>0.05) were found in cooking times between experimental and model values for either of the steaks. Modeled temperature profiles were consistently higher (except for the beginning of the cooking cycle) than the experimental values up to 65°C (150°F) in the cooking cycle for outside round steaks, whereas better agreement between experimental and modeled values was found for strip loin steaks. A highly positive linear relationship was found between experimental and modeled temperature histories for both strip loin (R^2=0.99) and outside round (R^2=0.96) steaks. The developed model should be useful for steak cooking, because the constant time to a given degree of doneness should increase consumer satisfaction by reducing variation in degree of steak doneness.

Introduction

Current practices in foodservice and restaurants do not rely on measurement of meat the temperature during cooking; rather, meat doneness is determined by visual observation. The problems associated with current practices are twofold: 1) the meat often is cooked to a higher endpoint temperature than intended, which results in customer dissatisfaction; or 2) the meat is cooked to a lower endpoint temperature than intended, which may cause food safety problems as well as customer dissatisfaction. Therefore, mathematical models have been used since the 1950's to predict cooking time or temperature profiles of meat during cooking. Earlier models were mostly based on predicting response variables such as cooking time, thermal conductivity, and beef tenderness from a measured property such as water content of the meat. Advances in computer technology have allowed scientists to develop computerized models. The objective of our study was to model cooking time and temperature profiles for oven roasting of beef strip loin or outside round steaks using a computerized mathematical model.

Experimental Procedures

In formulating the model, the following assumptions were made: 1) the steaks were homogenous and rectangular in shape; 2) the thermal conductivity, diffusivity, and heat capacity of the meat remain constant during the cooking cycle; 3) the heat transfer coefficient between hot air and meat remains constant; 4) heat transfer is considered for the thickness (x) and width (y) of the steaks; 5) energy required for melting of fat and protein denaturation is negligible; 6) the oven temperature is constant during the cooking cycle; and 7) evaporation of water is limited to the meat surface.

Cooking a steak in a forced-air convection oven includes a simultaneous heat and mass (mostly moisture) transfer in a continuously changing, complex porous structure. Therefore, both heat and mass transfer were used in modeling the cooking process. We individually cooked each strip loin and outside round steak in a gas-fired forced-air convection oven (Model DFG-102 CH3, G.S. Blodgett Co., Burlington, VT) at 163°C (325°F) until the center temperature of each steak, which was monitored with copper-constantan thermocouples (Omega Engineering, Stamford, CT) every 30 seconds, reached 70°C (160°F). Temperature profiles for each steak were recorded by a Doric temperature recorder, which was interfaced to a computer. The time and temperature data were imported into a spreadsheet. Oven temperature was also monitored. Cooking loss on each steak was calculated. Cooking time for each steak was measured as the time elapsed between placing a steak in the oven and removing a steak from the oven. The heat and mass transfer program was compiled in Fortran 77 computer language and executed under UNIX, which enabled us to have an exceptional execution speed.

A paired-T test using PROC UNIVARIATE option of SAS (version 8.12, 2000) was performed to test the differences between experimental and modeled temperature profile and cooking time.

Results and Discussion

Cooking time. We found no differences ($P>0.05$) between experimental and modeled cooking times for strip loin steaks (Table 1). However, the variance was greater for experimental values. Pearson's correlation coefficient (r) was very high (0.93), indicating a positive linear relationship between experimental and modeled cooking times.

We also detected no difference ($P>0.05$) in cooking times between experimental and modeled values for outside round steaks (Table 1). Variances for experimental and modeled cooking times were similar. There was a strong positive linear relationship (r = 0.95) between the experimental and modeled cooking times. In general, greater variation in cooking times (both for experimental and modeled) was noted for outside round steaks than for strip loin steaks.

Temperature profiles. Our model closely predicted temperature profiles for strip loin steaks (Figure 1). However, investigating how our model fits at a specific degree of steak doneness (very rare = 55ºC (130°F); rare = 60ºC (140°F); medium rare = 65ºC (150°F); and medium = 70ºC (160°F)) is more important. The difference between predicted and experimental steak temperature was about 3ºC (5°F) for a very rare steak, and about 2ºC (4°F) for a rare steak, both of which might be considered relatively small. The difference between predicted and experimental steak temperature was almost 0ºC (0°F) for either a medium rare or medium steak.

We also looked at the differences between experimental and predicted temperature values every 1 minute for the entire cooking cycle. Interestingly, half of the time the paired T-test revealed significant differences between experimental and predicted values. However, the model was accurate after 9 minutes in the cooking cycle, as differences between experimental and predicted values became smaller (Table 3). Agreement between experimental and predicted values late in the cooking cycle is more important than near the beginning because a steak commonly will not be eaten before its temperature is more than 55°C (130°F).

Our model over-predicted the temperature of outside round steaks (Figure 2), especially between 5 and 10 minutes into the cooking cycle with differences as large as 11°C (20°F) between experimental and predicted values. As cooking proceeded, the difference between experimental and predicted values became smaller, especially after 12 minutes, which corresponds to steak temperature of 65°C (medium rare). Thus, our model may not be applicable before this temperature. A paired T-test revealed predicted temperatures to be higher, which might restrict the use of the model. The use of modeling studies in meat cooking could minimize two costly problems, namely consumer dissatisfaction and food safety issues. Their success depends on more uniform, more highly controlled cooking.

Table 1. Experimental Versus Modeled Cooking Times for Strip Loin and Outside Round Steaks

	Strip Loin Steaks		Outside Round Steaks	
Steak #	Experimental	Modeled	Experimental	Modeled
	Cooking time (minutes)			
1	12.38	12.34	17.50	16.80
2	10.20	11.25	15.50	16.00
3	15.00	14.25	17.75	16.80
4	14.98	15.00	17.00	17.49
5	16.66	16.32	15.50	14.95
6	12.58	14.00	14.20	14.30
7	13.20	13.50	18.08	18.35
8	13.55	14.00	11.85	11.85
9	15.54	14.50	16.67	16.49
10	13.00	13.50	17.50	18.75

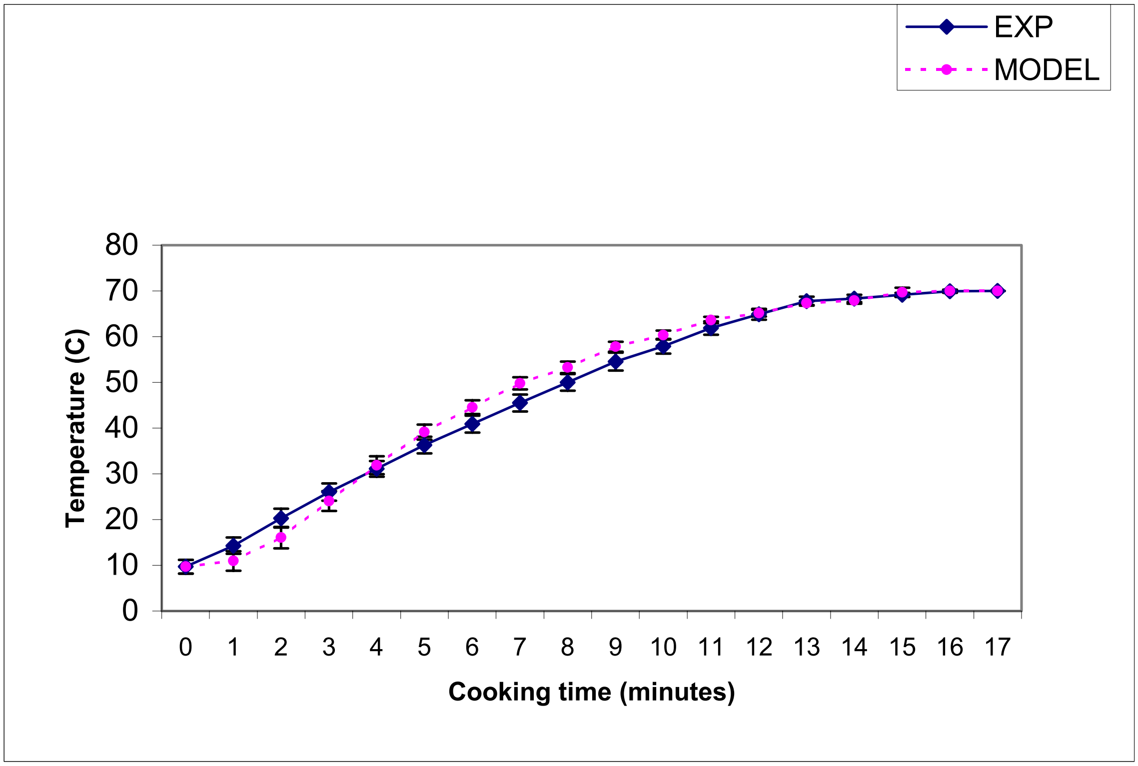

Figure 1. Experimental and Modeled Temperature Profiles for Strip Loin Steaks.

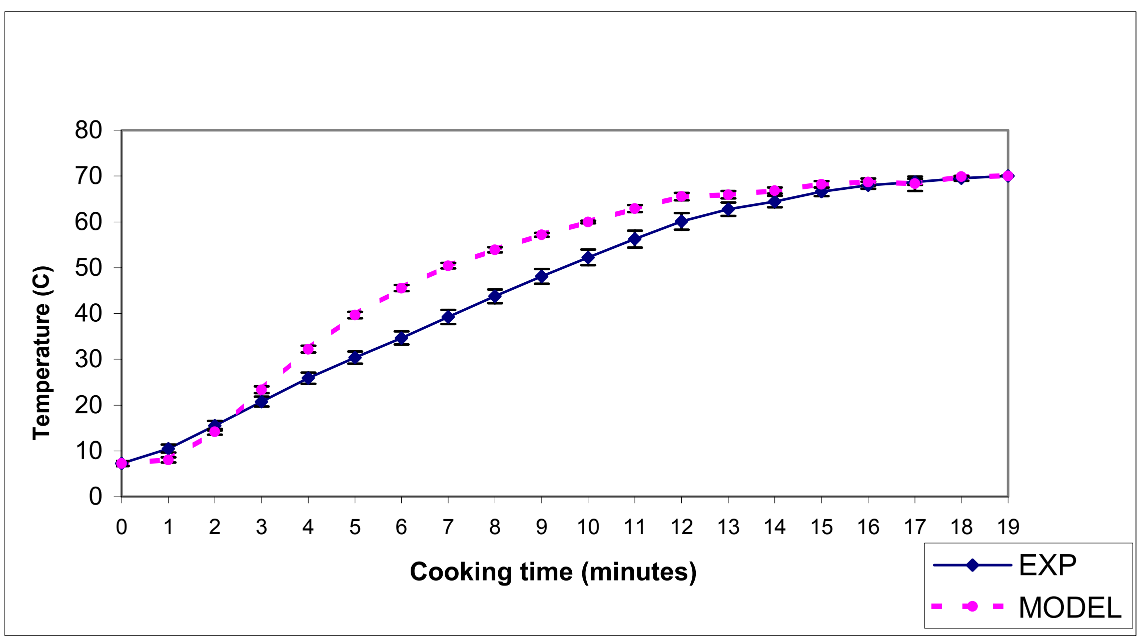

Figure 2. Experimental and Modeled Temperature Profiles for Outside Round Steaks.