A NEW APPROACH TO CORRELATE TEXTURAL AND COOKING PARAMETERS WITH OPERATING CONDITIONS DURING DOUBLE-SIDED COOKING OF MEAT PATTIES

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ABSTRACT

Cooking and textural parameters during double-sided cooking of hamburger patties were correlated with volume-averaged temperature at the end of the cooking process and gap thickness between plates. Frozen patties were cooked in a clamshell grill set at different plate surface temperatures (177C; 191C; 204C; 218C), for different gap thicknesses (9.65 mm; 10.05 mm; 10.55 mm; 11.05 mm) for 120 s. A decrease in the gap thickness and an increase in the plate surface temperature resulted in an increase in the cooking loss values (24-36%) and in a decrease of press juice values (8-25%). The values of peak load (183-215 N), modulus (16-19 N/mm), work needed in shearing (2300-2800 Nmm), hardness (25-32 N), cohesiveness (0.76-0.83), and chewiness (107-152 Nmm) of the patties increased when the gap thickness decreased and the plate surface temperature increased. There was no effect of the variables studied on springiness. The correlation equations involving the operating variables and quality parameters obtained are simple and useful in developing optimal process conditions.

INTRODUCTION

Ground beef is one of the most popular meat products consumed in the United States. Because of the relationship between undercooked hamburgers and *Escherichia coli* O157:H7 related disorders, the United States Department of Agriculture (USDA) and U.S. Food and Drug Administration (FDA) recommend that ground beef products be cooked to certain minimum temperatures to

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ensure their microbiological safety (71C for home preparation and 68C during 15 s for foodservice industries, respectively). However, it is difficult to measure the temperature at the slowest heating point in a product such as hamburger patties, especially at foodservice establishments. As a result, meat products may be overcooked with poor textural and sensory characteristics, or undercooked and microbiologically unsafe. Mathematical formulations may help to control and optimize the cooking process.

To optimize the hamburger patty cooking process, the objective function must take into account information related not only to microbial destruction, but also to the textural and sensory characteristics. In recent years, texture has become an important attribute indicative of the hamburger patty quality. Most of the research conducted measuring sensory and physical properties of beef patties involved the addition of texture-modifying ingredients (Brewer *et al.* 1992, Troutt *et al.* 1992a), fat substitutes (Ju and Mittal 1999), or changes in fat levels and cooking methods for the patties (Berry and Leddy 1984; Troutt *et al.* 1992b; Berry 1994). However, there is a lack of information in terms of textural or sensory parameters related to the main control variables of a defined cooking process.

Double-sided contact cooking is one of the commonly used methods for cooking hamburger patties in foodservice establishments (Dagerskog and Sörenfors 1978). During double-sided cooking of patties, the control variables that may be manipulated are: plate temperature, gap thickness between plates, and cooking time. The internal temperature in the patty changes with time and position during the process. As a result, different regions have different temperature histories (Zorrilla and Singh 2000). Temperature has an influence on textural properties of meat patties during cooking (Berry and Bigner-George 1999). An approach to consider the contribution of the different temperature profiles to the textural properties may be the use of volume-averaged temperatures (Mills 1999). Although volume-averaged temperatures are not easily measured by experimental methods, they have been used satisfactorily to obtain information for predicting heat transfer, refrigeration loads, and for optimizing freezing and thawing processes (Rubiolo 1996).

The volume-averaged temperature at the end of cooking time may also be related to internal temperature after a hamburger patty is removed from the grill (holding period). Previous studies involving texture measurements in cooked beef patties usually were carried out when the product was cooled to 25C (Berry and Bigner-George 1999; Miller *et al.* 1993). For the optimization process, it is important to have information as close as possible to the real cooking situation. Therefore, the texture measurements should be carried out immediately after cooking, during the first few minutes of the holding period.

The objective of this work was to correlate the textural and cooking parameters with the volume-averaged temperature and gap thickness between plates during double-sided cooking of meat patties in an attempt to relate the physical results to any change in the heat-transfer mechanism.

TABLE 1.
SUMMARY OF EQUATIONS TO DESCRIBE HEAT TRANSFER DURING DOUBLE-SIDED COOKING OF MEAT PATTIES[a]

Heat transfer in the core		
$\frac{\partial H(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(k(H)\frac{\partial T(H)}{\partial x}\right)$	$S_1(t) < x < S_2(t); t > 0$	(1)
Boundary conditions		
$T = T_h$	$x = S_1(t), S_2(t); t > 0$	(2)
Initial condition		
$T = T_0$	$t = 0; S_1(t) < x < S_2(t)$	(3)
Interfacial balance		
$-k_{crust}\frac{\partial T_{crust}}{\partial x} + k\frac{\partial T}{\partial x} = \lambda_v \rho m \frac{dS_i(t)}{dt}$	$x = S_i(t); t > 0; i = 1, 2$	(4)
Heat balances at surface		
$-k_{crust}\frac{\partial T_{crust}}{\partial x} = h\left(T_{p1}(t) - T_{crust}\right)$	$x = 0; t > 0$	(5)
$-k_{crust}\frac{\partial T_{crust}}{\partial x} = h\left(T_{crust} - T_{p2}(t)\right)$	$x = L; t > 0$	(6)

[a] Zorrilla and Singh (2000).

THEORY

Prior to cooking, hamburger patties are either in frozen or completely thawed state. When a frozen hamburger patty is placed on a grill (at T > 160C) the heat is transferred from the grill surface into the patty. The cooking process starts and as far as heat penetrates the patty, solid fat and ice melt. Near the patty surface, the temperature exceeds 100C, water evaporates, and, by a combination of dehydration and browning reactions, the formation of a crust takes place. Water and fat are released from the patty affecting mainly the heat-transfer resistance between the patty and the hot plate. A solid-liquid interface (during melting) and a liquid-vapor interface (during evaporation) can be assumed when a frozen hamburger patty is cooked by contact. Thus, the problem can be studied as a multiphase moving-boundary one (Singh 2000).

Volume-averaged Temperature

The one-dimensional heat transfer model used to describe the phenomena that occur during hamburger patty cooking by double-sided contact (Zorrilla and Singh 2000) is summarized in Table 1. The model solution allows us to obtain the temperature histories at different locations in the patty. A volume-averaged temperature, $\bar{T}$, can be defined as:

$$\bar{T}=\frac{\iiint_V T(x,t)dV}{\iiint_V dV}=\frac{\int_0^L T(x,t)dx}{L} \tag{7}$$

where T(x,t) is the temperature profile inside the patty, and L is the gap thickness between plates. The integral in Eq. (7) can be evaluated numerically using the temperatures obtained for the different discrete points or nodes considered in the numerical solution of the original model. The volume-averaged temperature represents the equilibrium temperature that the patty would reach after cooking if it were placed in an insulated chamber.

Holding Period

When a patty is removed from the grill, the heat continues penetrating into the patty because a temperature gradient exists between the center and the plane surface of the patty. Since the patty is completely thawed, Eq. (1) can be changed to the classical transient heat transfer equation. Core/crust interface does not move but the heat transfer continues. The heat flux through the core must equal that through the crust region:

$$k_{crust}\frac{\partial T_{crust}}{\partial x}=k\frac{\partial T}{\partial x} \qquad x=S_1,\ S_2;\ t>0 \tag{8}$$

Considering the convective heat flux from the surface of the crust to the air and the conductive heat within the crust to be equal,

$$\pm k_{crust}\frac{\partial T_{crust}}{\partial x} = h_c(T_{crust}-T_a) \qquad x = 0, L;\ t>0 \tag{9}$$

where h_c is the convective heat transfer coefficient during the holding period, and T_a is the air temperature. The temperature profile inside the patty, obtained at the end of the cooking process was considered as the initial condition for the holding period.

MATERIALS AND METHODS

Frozen hamburger patties (24% fat content, 60% w.b. moisture, 16% protein content, 12.5 mm thickness, 118 mm diameter, 116 g weight) were shipped in insulated containers packed with dry ice from a patty manufacturing plant. Patties were kept frozen for a maximum of 2 days in a walk-in freezer at -30C before the experiments.

Frozen patties were removed from the freezer and immediately cooked in a commercial, double-sided, clamshell grill (Taylor, Rockton, IL) at four different plate temperatures (177C, 191C, 204C, and 218C) for 120 s. Both bottom and top plates were set to same temperatures. Fourteen thermocouples were previously located in the grill plates by the grill manufacturer to measure the plate surface temperatures (5 thermocouples located in top plate and 9 in bottom plate). Temperatures were monitored using a data acquisition system consisting of a PC computer, DataShuttle DS-16-8-TC and DasyLab Version 5.0 software (IOtech Inc., Cleveland, OH). Four different gap thicknesses between plates were considered: 9.65 mm, 10.05 mm, 10.55 mm, and 11.05 mm. The gap thickness was measured in triplicate at four different positions using a device provided by the grill manufacturer and a micrometer 0 to 1 in. (Scherr, Tumico Inc., MN).

The grill plates were heated to the chosen set temperature. Hamburger patties were placed on the bottom plate, the top plate was lowered to a pre-selected set gap thickness, and the cooking process was started. Six hamburger patties were cooked in each batch, but only three of them were used to perform the studies on texture, juiciness, and cooking loss. The cooking and textural measurements were carried out immediately after the patties were removed from the grill.

Cooking Parameters

Cooking Losses. Percentage of cooking loss was evaluated by calculating weight differences for patties before and after cooking, as follows:

$$\text{Cooking loss} = \frac{\text{mass of raw patty} - \text{mass of cooked patty}}{\text{mass of raw patty}} \times 100 \quad (10)$$

Three replicates were conducted for each treatment studied.

Press Juice. The juiciness of the samples was determined using a method adapted from a procedure described by Ju and Mittal (1999). A 23-mm-diameter cylindrical sample of cooked patty was removed using a core borer. After cutting with a knife in tiny pieces, 1 g sample was placed between a pair of aluminum foil sheets 7 cm diameter. Two pieces of filter paper (Whatman No. 5, 15 cm diameter, Whatman International Ltd., Maidstone, U.K.) and a pair of plexiglass plates (15 × 15 cm) covered the aluminum foil. Then, the whole set was placed in an Instron Universal Testing Machine (Model 1122, Instron Corp., Canton, MA). A 4300-N force was applied to the set for 2 min. The filter paper was weighed before and after pressing, and the mass of the extracted juice was determined. The press juice was calculated as follows:

$$\text{Press juice} = \frac{m_a - m_b}{\text{sample mass}} \times 100 \quad (11)$$

where m_a is the mass of the filter paper after pressing and m_b is the mass of the filter paper before pressing. Three replicates were conducted for each treatment studied.

Textural Studies

The texture of the hamburger patties was analyzed using a Texture Analyzer TA.XT2™ (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Haslemere, Surrey, UK) immediately after cooking.

Modified Texture Profile Analysis (TPA). Three 23-mm-diameter cylinders were removed from each patty with a core borer. Each core was compressed twice to 5 mm height using a 40-mm-diameter aluminum cylinder probe at a speed of 5 mm/s. Analysis of the resulting two force deformation curves (Texture Expert for Windows 1.0, Stable Micro Systems Ltd. 1995, Haslemere, Surrey, UK) yield the following textural parameters: hardness (N) which is the maximum force during the first compression; cohesiveness (dimensionless), defined as the ratio of positive force area during the second compression to that during the first compression; springiness (mm), which is the height that the food recovers after the first compression; and chewiness (Nmm), which is the product of hardness, cohesiveness and springiness. Eighteen replicates were conducted for each treatment studied.

Kramer Shear Press. A Kramer shear probe with five blades was used for the experiments at a speed of 5 mm/s. A 61 mm × 80 mm section was removed from each patty using a sharpened stainless-steel borer to fit the sample in the Kramer cell sample holder. Instrumental values using Texture Expert for Windows 1.0, obtained from the shear force test included: peak load (N), which is the maximum force and provides an index of the forces to break into the food in combination with adhesive and cohesive effects; work to shear (Nmm), which is the positive force area under the force-displacement curve and represents the energy required to break the sample; and modulus (N/mm), which is the slope of the linear portion of the ascending force curve and represents the firmness characteristics of the patty. Nine replicates were conducted for each treatment studied.

Statistical Analysis

The experimental design considered two factors: grill temperature (177C, 191C, 204C, 218C), and gap thickness between plates (9.65 mm, 10.05 mm, 10.55 mm, 11.05 mm). From the combination of factors and levels, 16 treatments were performed for this study.

Data were analyzed using analysis of variance procedure of the General Linear Model (SAS Institute, Inc. 1999). Grill temperature and gap thickness were considered fixed effects. When treatment effects were significant ($P < 0.05$), differences between mean values were evaluated by Duncan's Multiple Range test (SAS Institute, Inc. 1999). Correlation equations were obtained using surface-fit simple equations (TableCurve™ 3D, version 2, AISN Software Inc.).

Simulation

A computer program was written in *Digital Visual Fortran Version 5.0*. The input data were similar to the data reported by Zorrilla and Singh (2000): gap thickness between plates, product composition, unfreezable water content, initial freezing point, initial temperature of the product, plate temperature history, contact heat transfer coefficient, and total cooking time. The convective heat transfer coefficient and surrounding air temperature during the holding period were also included. Thermal properties varying with temperature were calculated using the procedure developed by Mannapperuma (1988) based on composition, unfreezable water content, and initial freezing point. The physical and thermal properties used are given in Table 2.

TABLE 2.
PHYSICAL AND THERMAL PROPERTY DATA OF HAMBURGER PATTY FOR THE MODEL SIMULATION

Property	Value	Source
Density	1027 kg/m^3	(a)
Apparent specific heat	3268 J/kg °C	(a)
Thermal conductivity	0.416 W/m °C	(a)
Unfreezable water	4%	(a)
Initial freezing point	-1 C	(a)
T_{p1}; T_{p2}	Values measured in experiment	
L	Value measured in experiment	
h	Experimental values changing with time	(b)
h_c	30 W/m^2 °C	(c)
T_a	25 C	(c)

(a) Properties for the unfrozen state based on the composition (Valentas *et al.* 1997); (b) Wichchukit (2000); (c) Assumed for this study.

RESULTS AND DISCUSSION

The myofibrils that provide the larger structural framework in meat are broken down into smaller pieces when meat is comminuted (Offer and Knight 1988). Therefore, comminuted meats tend to exude fluid more easily than intact meat because the meat structure has been destroyed (Lawrie 1991). The water content and its distribution have a major influence on the properties of meat products, especially toughness, juiciness, firmness, and appearance.

Table 3 shows the cooking loss values that represent the amount of moisture and melted fat released from the patties during cooking. Cooking loss values increased as plate temperature increased and gap thickness decreased. Bertola *et al.* (1994) and Martens *et al.* (1982) reported that cooking loss increased with temperature during cooking of meat. Lawrie (1991) found that high temperatures cause protein denaturation and a considerable lowering in water-holding capacity. Therefore, the fact that cooking loss values increased as grill surface temperatures increased may be explained considering the decrease of water-holding capacity and the increased availability of water to be evaporated. As gap thickness between plates decreases, more water and fat may be squeezed out, resulting in higher cooking loss values. Part of the moisture and melted fat present in the sample can be pressed out as juice. Values for juiciness are inversely correlated with cooking loss (Table 3).

TABLE 3.
MEAN VALUES OF COOKING PARAMETERS

Grill temperature (°C)	Gap thickness (mm)	Cooking loss (%)	Press juice (%)
177	9.65	28.6^{efg}	17.8^{bcde}
	10.05	29.1^{ef}	18.5^{bcde}
	10.55	24.8^{hi}	23.5^{ab}
	11.05	23.9^{i}	21.7^{abc}
191	9.65	32.0^{bc}	14.3^{def}
	10.05	29.2^{e}	18.5^{bcde}
	10.55	27.6^{efg}	21.5^{abc}
	11.05	26.5^{gh}	17.7^{bcde}
204	9.65	31.4^{cd}	20.4^{abcd}
	10.05	32.1^{bc}	15.6^{cde}
	10.55	27.9^{efg}	19.8^{abcd}
	11.05	27.0^{fg}	25.5^{a}
218	9.65	36.3^{a}	8.2^{f}
	10.05	33.9^{b}	15.7^{cde}
	10.55	34.0^{b}	12.5^{ef}
	11.05	29.5^{de}	22.6^{abc}
SEM		0.2	0.6

Means in the same column with the same superscript letter are not significantly different ($P < 0.05$).

SEM: Standard error of the mean.

Figure 1 shows the typical Texture Profile Analysis curve for beef patties. No adhesiveness or fracturability was observed. The area and height of the second bite are similar to those of the first bite. Similar profiles were reported by Bourne (1978) for cooked beef and beef analog made from spun soy fiber. Table 4 shows the values obtained from the Texture Profile Analysis of cooked hamburger patties for the treatments studied.

Changes in the textural properties of meat during cooking are generally associated with changes in collagen (main protein of the connective tissue) and myofibrillar proteins induced by heat. Martens *et al.* (1982) studied the textural changes produced during meat cooking related to heat denaturation of the main protein systems. Given that such heat denaturation seems to occur at different temperature ranges, it is important to analyze the changes in texture of a beef patty based on the internal temperature profiles for each treatment.

The computer-predicted internal temperature profiles at the end of the cooking period for 177C set grill temperature and different gap thicknesses are shown in Fig. 2. As the gap thickness between plates decreased, the center temperature increased. Smaller gap thickness leads to a thicker crust (as seen in Fig. 2 when portions of the curves at temperatures higher than 100C are compared). Similar behavior was observed for the other set grill temperatures studied. When plate temperature increased, center temperature increased, as expected. The overall water-holding capacity drops markedly as the temperature increases between 80 and 100C (Lawrie 1991), and meat becomes hard and dried even though the connective tissue is softened (Martens *et al.* 1982). It seems reasonable to expect that as cooking loss increases, patties become harder and more difficult to chew (higher cohesiveness) with increasing temperature, as shown in Table 4.

The rest of the parameters from the Texture Profile Analysis are also shown in Table 4. Values for springiness were constant for all the conditions tested, while chewiness tended to increase with increasing plate temperature and decreasing gap thickness, similar to hardness values.

Figure 3 shows the typical force-deformation curve obtained from the Kramer shear test. The results from the Kramer shear press are shown in Table 5. The maximum force, which is a combination of compression and shearing, may increase because a thicker crust develops when a smaller gap thickness or a higher plate temperature are used. The modulus is related to the firmness of the patty, which may be related to a combination of such factors as cooking loss, crust formation, and internal temperature profiles. Therefore, the work to shear and the firmness may increase because cooking losses increase and crust thickness increases when the gap thickness decreases or the plate temperature increases.

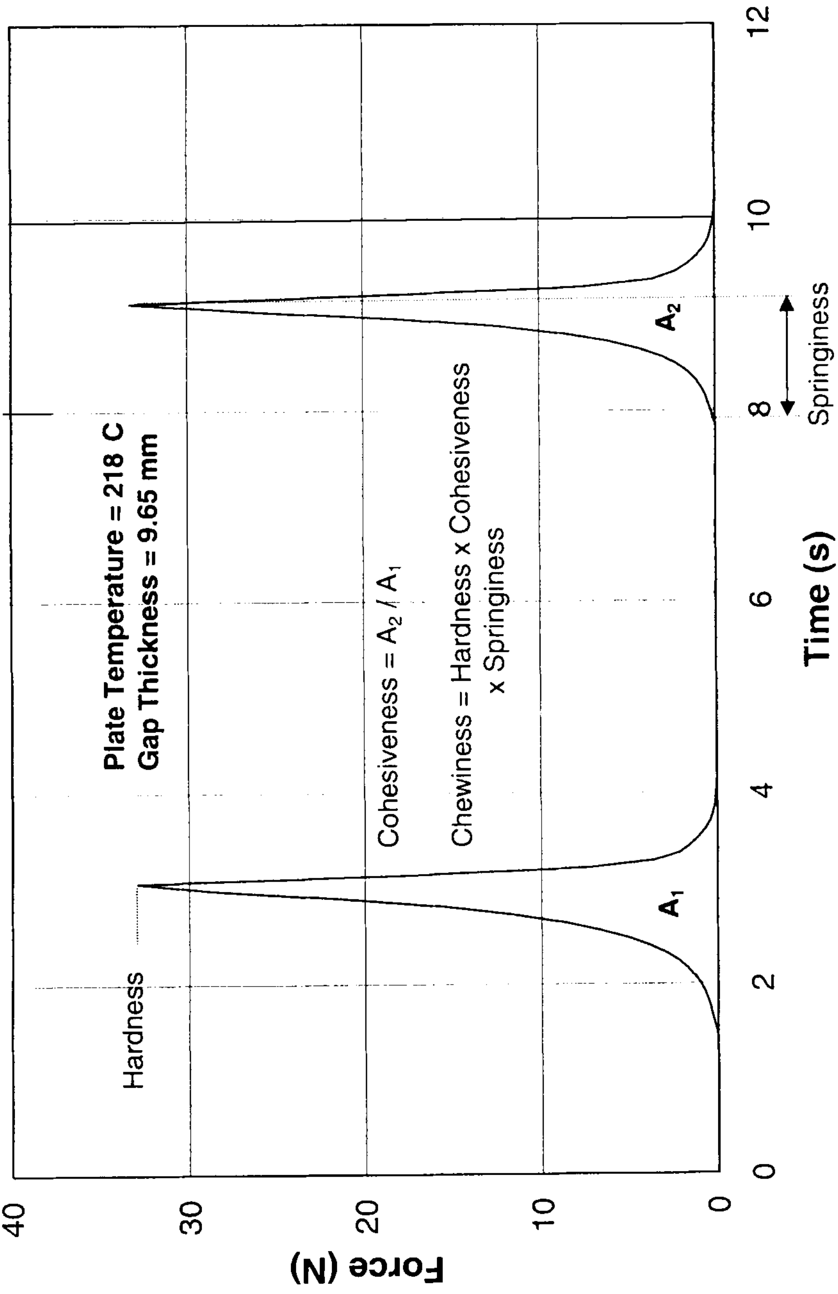

FIG. 1. TYPICAL TEXTURE PROFILE CURVE FOR THE CASES STUDIED

TABLE 4.
MEAN VALUES OF TEXTURAL PARAMETERS (TPA)

Grill temperature (°C)	Gap thickness (mm)	Hardness (N)	Cohesiveness	Springiness (mm)	Chewiness (Nmm)
177	9.65	27.4^{def}	0.819^{ab}	5.36^{a}	121^{cde}
	10.05	29.6^{bcde}	0.794^{cd}	5.43^{a}	129^{abcde}
	10.55	28.2^{cdef}	0.780^{de}	5.48^{a}	121^{cde}
	11.05	26.0^{ef}	0.780^{de}	5.48^{a}	112^{de}
191	9.65	30.6^{abcd}	0.815^{ab}	5.41^{a}	136^{abcd}
	10.05	28.3^{cdef}	0.780^{de}	5.42^{a}	120^{cde}
	10.55	26.0^{ef}	0.812^{abc}	5.38^{a}	114^{cde}
	11.05	24.2^{f}	0.807^{bc}	5.50^{a}	110^{e}
204	9.65	27.2^{def}	0.828^{a}	5.18^{a}	118^{cde}
	10.05	33.3^{ab}	0.816^{ab}	5.55^{a}	152^{a}
	10.55	30.8^{abcd}	0.817^{ab}	5.38^{a}	137^{abc}
	11.05	28.2^{cdef}	0.794^{cd}	5.40^{a}	122^{bcde}
218	9.65	32.1^{abc}	0.826^{ab}	5.46^{a}	145^{ab}
	10.05	34.6^{a}	0.773^{e}	5.49^{a}	147^{a}
	10.55	30.6^{abcd}	0.813^{abc}	5.51^{a}	138^{abc}
	11.05	28.6^{cde}	0.806^{bc}	5.34^{a}	124^{bcde}
SEM		0.3	0.002	0.03	2

Means in the same column with the same superscript letter are not significantly different ($P < 0.05$).

SEM: Standard error of the mean.

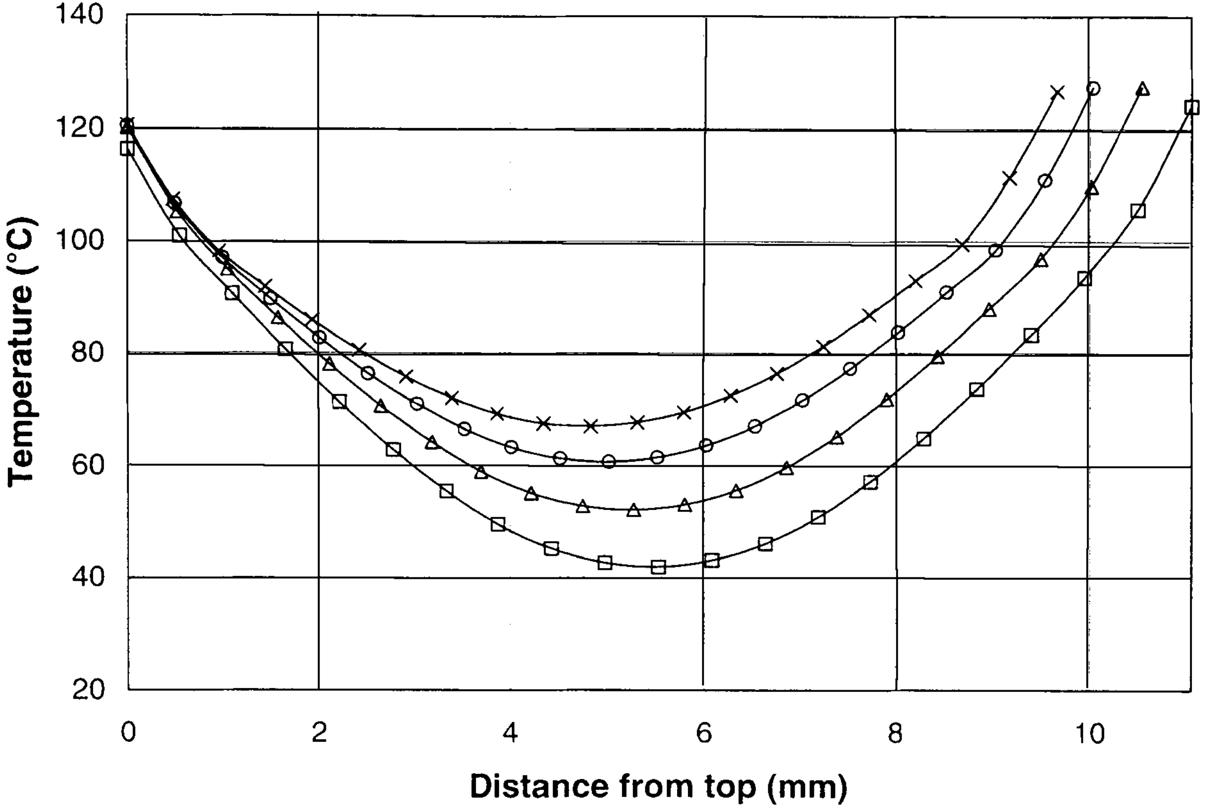

FIG. 2. SIMULATED TEMPERATURE PROFILES AT THE END OF COOKING TIME FOR 177C SET GRILL TEMPERATURE AND FOR THE DIFFERENT GAP THICKNESSES:
(×) 9.65 mm; (o) 10.05 mm; (Δ) 10.55 mm; (□) 11.05 mm.

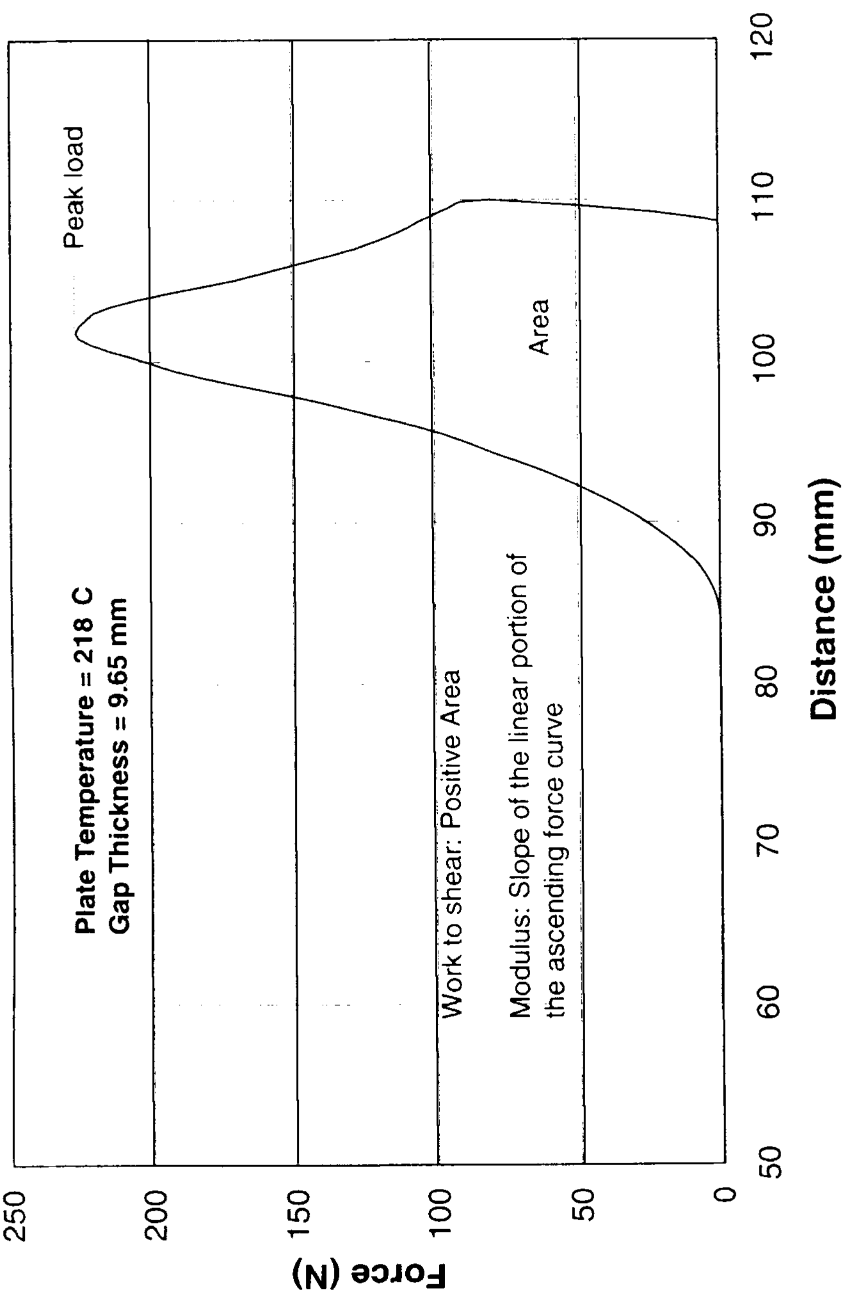

FIG. 3. TYPICAL KRAMER SHEAR PROFILE FOR THE CASES STUDIED

TABLE 5.
MEAN VALUES OF TEXTURAL PARAMETERS (KRAMER SHEAR PRESS)

Grill temperature (°C)	Gap thickness (mm)	Peak load (N)	Work to shear (Nmm)	Modulus (N/mm)
177	9.65	211^{abc}	2565^{abc}	19.5^{a}
	10.05	196^{bc}	2408^{bc}	17.4^{abc}
	10.55	186^{bc}	2340^{bc}	16.5^{abc}
	11.05	190^{bc}	2369^{bc}	17.0^{abc}
191	9.65	209^{abc}	2618^{ab}	18.0^{abc}
	10.05	211^{abc}	2661^{ab}	18.1^{abc}
	10.55	188^{bc}	2378^{bc}	16.0^{c}
	11.05	184^{c}	2269^{c}	16.2^{c}
204	9.65	212^{abc}	2646^{ab}	18.5^{abc}
	10.05	209^{abc}	2589^{abc}	18.0^{abc}
	10.55	205^{abc}	2572^{abc}	17.7^{abc}
	11.05	198^{abc}	2491^{bc}	16.4^{bc}
218	9.65	215^{ab}	2634^{ab}	18.6^{abc}
	10.05	226^{a}	2857^{a}	19.4^{ab}
	10.55	212^{abc}	2670^{ab}	18.8^{abc}
	11.05	206^{abc}	2554^{abc}	17.1^{abc}
SEM		2	26	0.2

Means in the same column with the same superscript letter are not significantly different ($P < 0.05$).

SEM: Standard error of the mean.

Typical temperature profiles obtained by simulation as a function of axial position at the end of cooking time and for selected times during the holding period (when the plate temperature is set at 191C and the gap thickness between plates is set at 10.55 mm) are shown in Fig. 4. During the first 60 s of the holding period, the temperature at the center position increases while the temperature at the edges decreases trying to reach a uniform temperature. After 60 s, the temperature starts decreasing to reach the ambient temperature. The volume-averaged temperature at the end of cooking time is 78C. Although the volume-averaged temperature is a fictitious temperature, it is close to the temperature value that the patty will reach during the first minutes after it is removed from the grill, which is also the approximate time delay necessary to carry out the textural measurements. Therefore, the volume-averaged temperature may be conveniently correlated with quality parameters to be included in optimization processes. The volume-averaged temperatures for the treatments studied are shown in Fig. 5. As in the case of the center temperature, the volume-averaged temperature decreased as the gap thickness increased for the same set plate temperature.

There were significant effects of plate temperature and gap thickness in all of the parameters studied except springiness. Therefore, those parameters affected were correlated with the corresponding volume-averaged temperatures and gap thicknesses. The correlation equations are shown in Table 6. As shown, the variation in cooking loss and textural parameters from the Kramer shear press test were better explained by the fitted equations considering the higher correlation coefficients obtained for those cases.

Figures 6 to 8 show the experimental quality parameters and the corresponding regression surfaces related to volume-averaged temperature and gap thickness. In Fig. 6A, when a constant gap thickness is considered and the volume-averaged temperature increases, the cooking loss increases. Also, with a constant volume-averaged temperature and decreasing gap thickness, the cooking loss decreases. To keep the same volume-averaged temperature for a smaller gap thickness, it is necessary to decrease the plate surface temperature and then, the cooking loss decreased. An inverse behavior is observed in the case of press juice (Fig. 6B). However, when a constant volume-averaged temperature is considered, the influence of the gap thickness is not so profound as in the case of the cooking loss, indicating that the press juice may not be as sensitive to gap thickness changes.

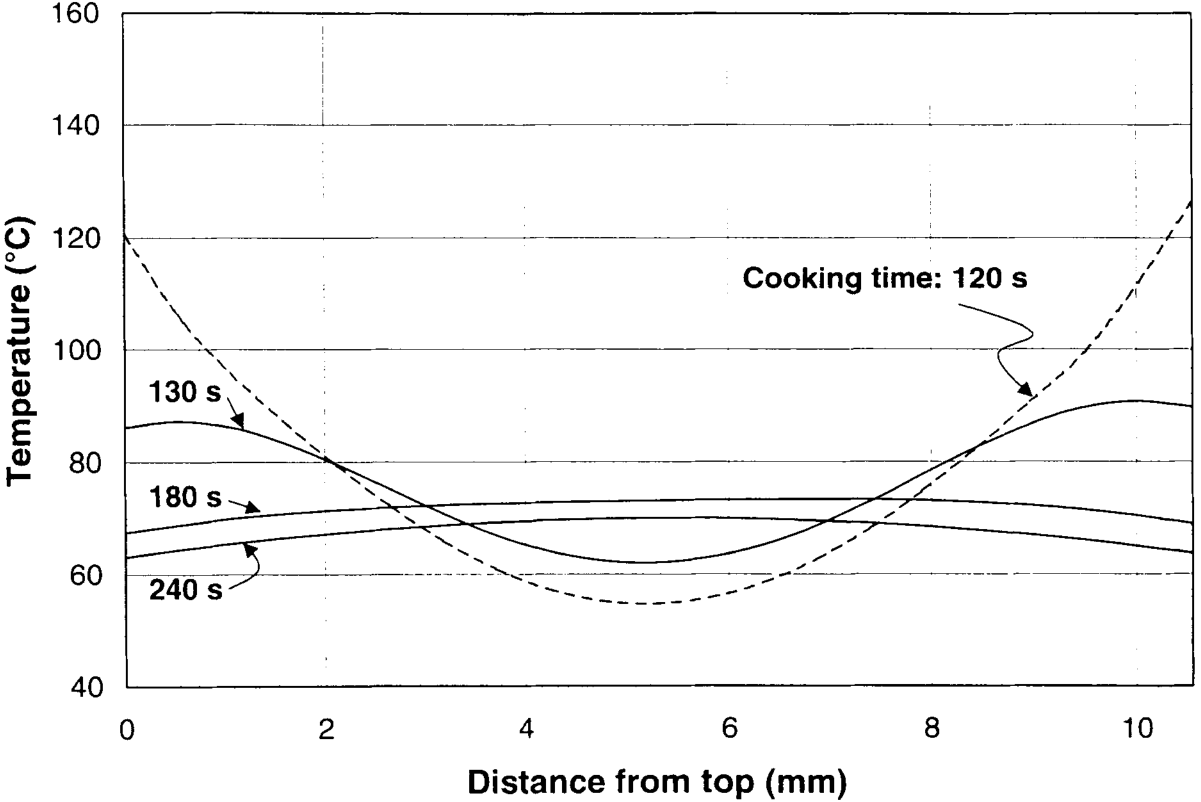

FIG. 4. SIMULATED TEMPERATURE PROFILES AT THE END OF COOKING TIME AND AT DIFFERENT TIMES DURING THE HOLDING PERIOD WHEN THE PLATE TEMPERATURE IS SET AT 191C AND THE GAP THICKNESS BETWEEN PLATES IS SET AT 10.55 mm

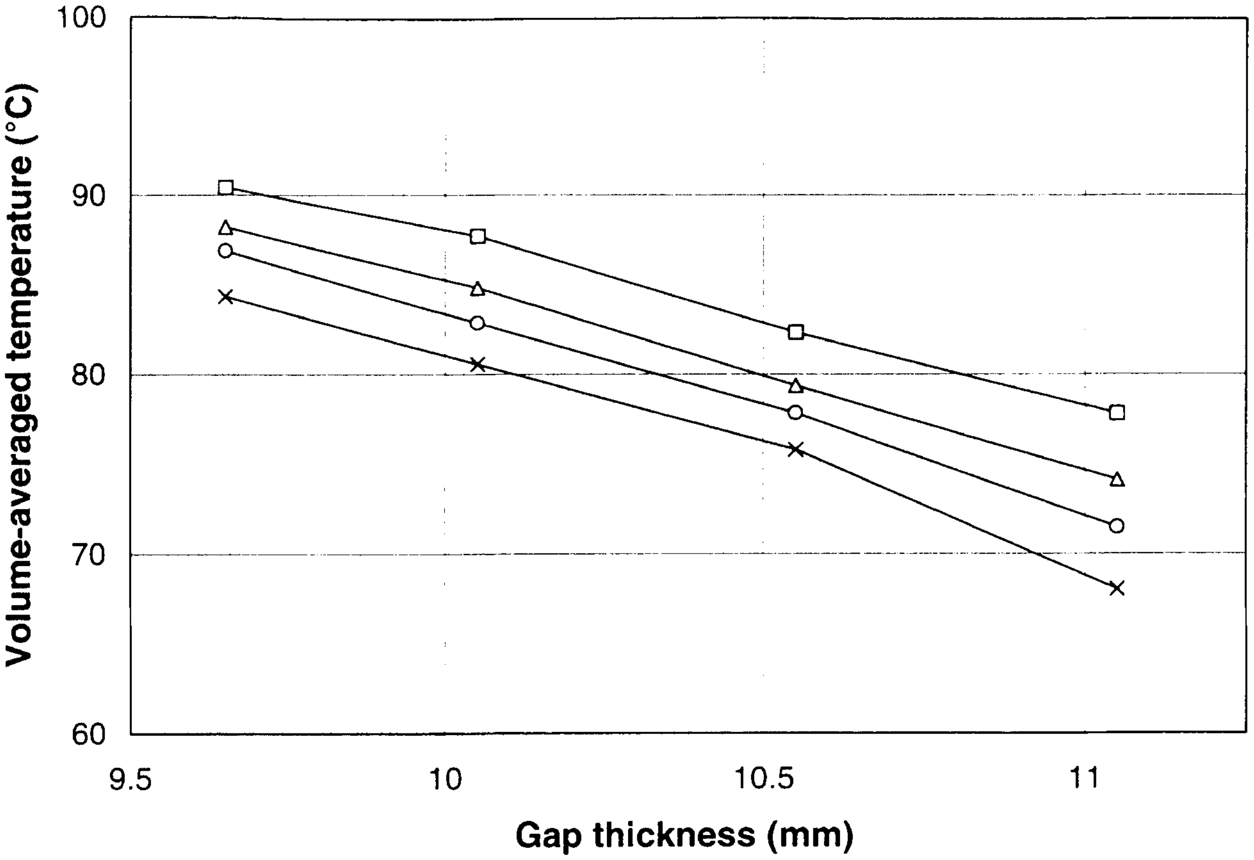

FIG. 5. VOLUME-AVERAGED TEMPERATURE CALCULATED FOR THE 16 TREATMENTS STUDIED
Plate surface temperatures: (×) 177C; (o) 191C; (Δ) 204C; (□) 218C.

TABLE 6.
CORRELATION EQUATIONS RELATING $\bar{T}$ AND L WITH COOKING AND TEXTURAL PARAMETERS

Response (z)	Regression equation (a)	r^2 (b)
Cooking loss (%)	$z = -122.25 + 4.56\ 10^{-5}\bar{T}^3 + 54.59 \ln L$	0.90
Press juice (%)	$z = 63.29 - 0.50\bar{T} - 0.46L$	0.45
Hardness (N)	$z = -55.89 + 0.58\bar{T} + 3.73L$	0.55
Cohesiveness	$z = 0.88 - 7.03/\bar{T} + 0.12/L$	0.19
Chewiness (Nmm)	$z = -260.78 + 2.65\bar{T} + 16.94L$	0.54
Peak load (N)	$z = -144.73 + 2.61\bar{T} + 13.31L$	0.78
Work to shear (Nmm)	$z = -2468.19 + 35.03\bar{T} + 210.84L$	0.74
Modulus (N/mm)	$z = 10.43 + 0.12\bar{T} - 0.24L$	0.63

(a) $\bar{T}$ (°C); L (mm).

(b) Correlation coefficient.

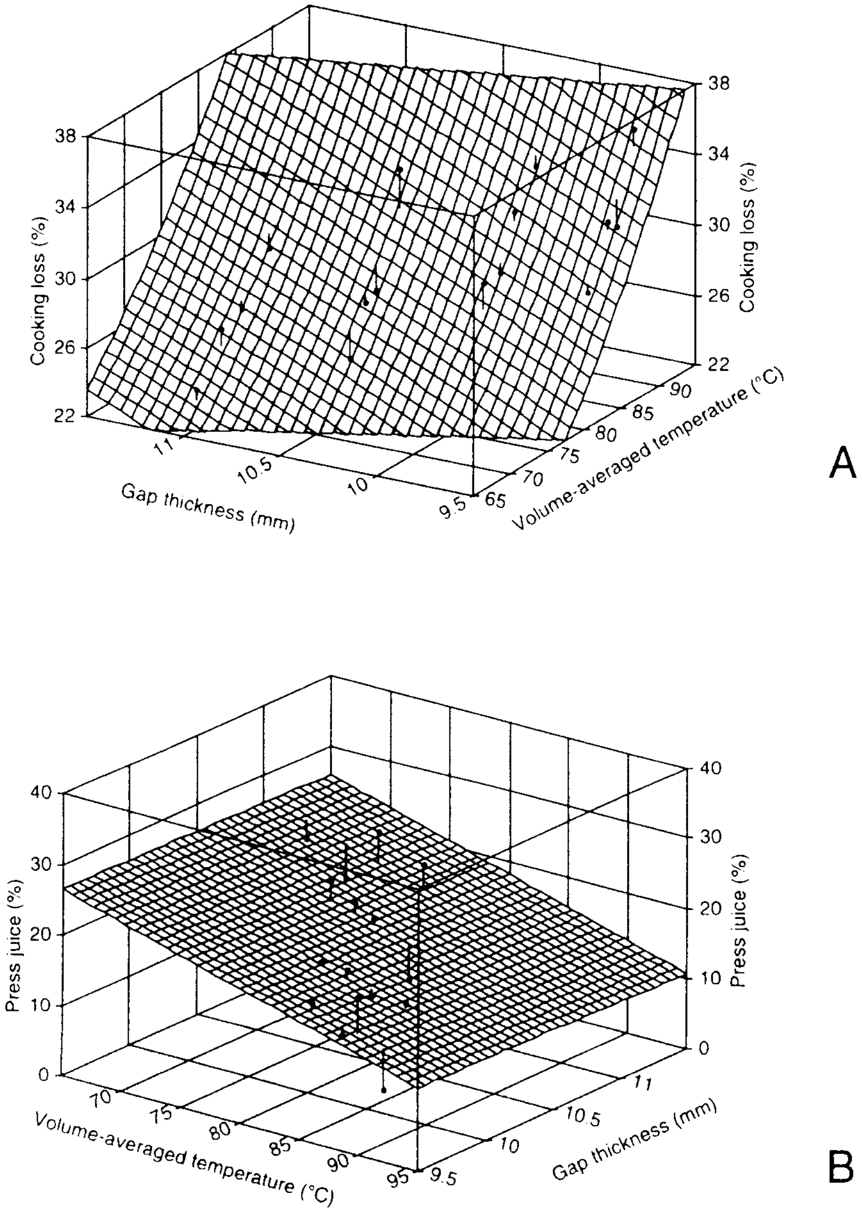

FIG. 6. COOKING PARAMETERS CORRELATED WITH VOLUME-AVERAGED TEMPERATURE AND GAP THICKNESS:
(A) Cooking loss; (B) Press juice.

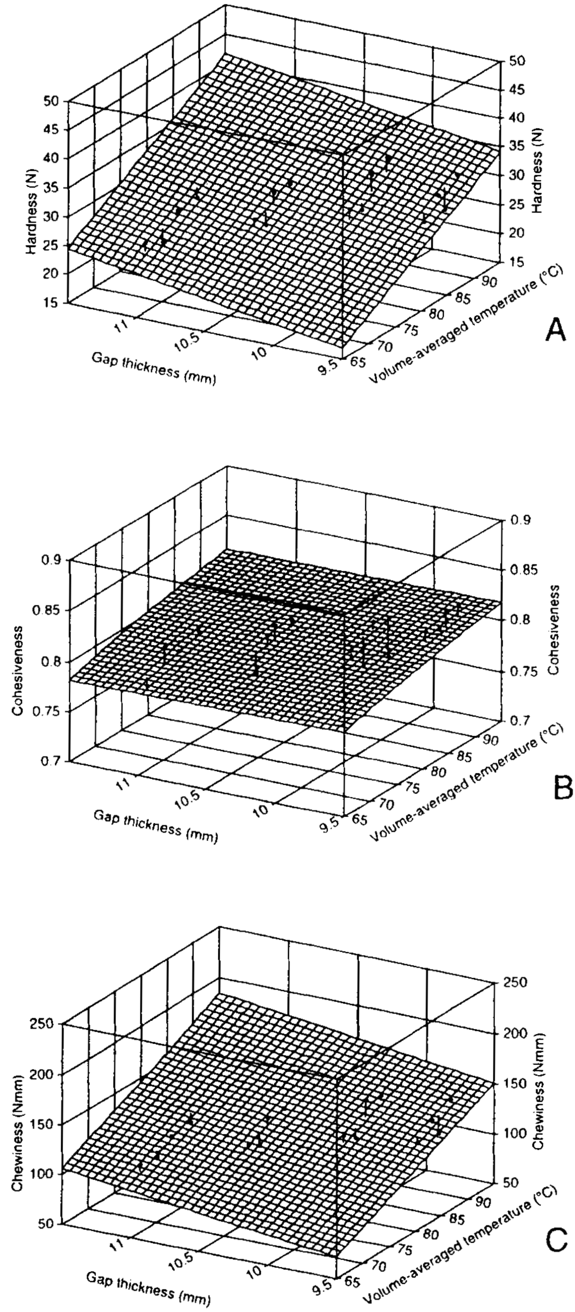

FIG. 7. TPA PARAMETERS CORRELATED WITH VOLUME-AVERAGED TEMPERATURE AND GAP THICKNESS:
(A) Hardness; (B) Cohesiveness; (C) Chewiness.

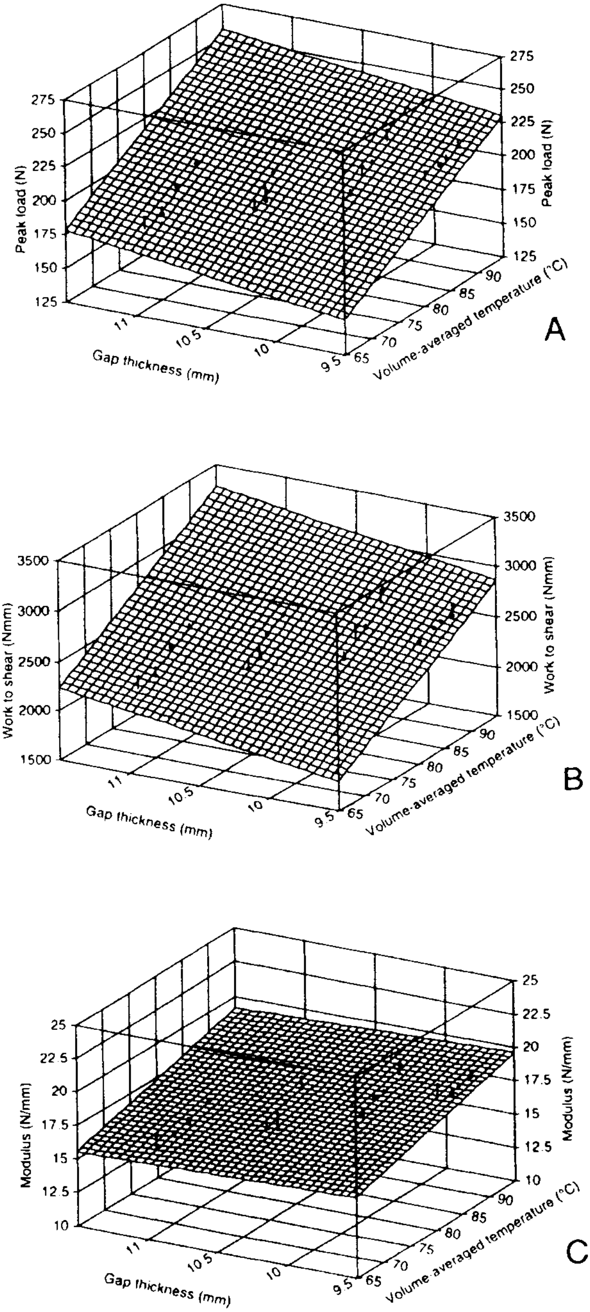

FIG. 8. KRAMER SHEAR PARAMETERS CORRELATED WITH VOLUME-AVERAGED TEMPERATURE AND GAP THICKNESS:
(A) Peak load; (B) Work to shear; (C) Modulus.

Figure 7 shows how the parameters obtained from the Texture Profile Analysis change with volume-averaged temperature and gap thickness. The changes in these parameters are similar to those seen for cooking loss. In this case, hardness and chewiness (Fig. 7A and 7C, respectively) are more sensitive to gap thickness changes than cohesiveness (Fig. 7B). Figure 8 shows the parameters obtained from Kramer shear press test as function of volume-averaged temperature and gap thickness. Similar behavior as seen in cooking loss is observed. In this case, peak load and work to shear (Fig. 8A and 8B, respectively) are more sensitive to gap thickness changes than modulus (Fig. 8C).

Textural quality attributes are important for the consumer acceptability of food products. Therefore, the equations determined in this work may be incorporated into future mathematical models for optimization of hamburger patty cooking. Such optimization studies are necessary to design improved grills and processes.

CONCLUSIONS

A decrease in gap thickness between plates from 11.05 mm to 9.65 mm and/or an increase in plate temperature from 177C to 218C resulted in an increase of cooking loss (24-36%), hardness (25-32 N), cohesiveness (0.76-0.83), chewiness (107-152 Nmm), peak load (183-215 N), modulus (16-19 N/mm), and work to shear (2300-2800Nmm); and a decrease in juiciness (8-25%).

Equations correlating cooking and textural parameters with volume-averaged temperature at the end of the cooking process and gap thickness between plates were obtained with correlation coefficients from 0.19 to 0.90. Cooking losses and textural parameters determined using the Kramer shear press were better correlated ($r^2 > 0.6$).

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NOMENCLATURE

h	Contact heat transfer coefficient, W/m^2 °C
h_c	Convective heat transfer coefficient, W/m^2 °C
H	Enthalpy, J/m^3
k	Thermal conductivity in the core, W/m °C
k_{crust}	Crust thermal conductivity, W/m °C
m	Moisture content, decimal
L	Gap thickness, m
S_1, S_2	Positions of moving boundary that separates the crust region from the core one, m
t	Time, s
T	Temperature, °C
T_a	Air temperature, °C
T_b	Boiling temperature, °C
T_{p1}, T_{p2}	Plate temperatures, °C
T_0	Initial temperature, °C
x	Space coordinate perpendicular to the patty plate surface, m

Greek letters

λ_v	Latent heat of water vaporization, J/kg
ρ	Hamburger patty density, kg/m^3

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