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A COMPARISON OF NUMERICAL TECHNIQUES TO CALCULATE BROKEN LINE HEATING FACTORS OF A THERMAL PROCESS

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ABSTRACT

Numerical methods comprised of least squares, rational functions, minmax, and cubic spline were used in conjunction with comparisons of ratios of slopes and coefficient of determination (R^2) to define the location of the 'break' in a broken line heating curve for canned bean and potato products. From these breaks, the process times B_b were evaluated. These times were not statistically different from the time determined from the same data that had been handplotted. For the rational function method, the approximations and slope ratio curves were quite smooth, although at times the method was sensitive to minor variations in the data points. The cubic spline approximation demonstrated a very smooth curve, a desirable characteristics of this method, but the slope ratio curves from this method fluctuated excessively.

INTRODUCTION

To ensure commercial sterility in low acid canned foods, processing parameters, such as initial temperature, retort temperature, can size, heating time, fill weight, and brine consistency, must be established. Based on the *Laboratory Manual for*

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Food Canners and Processors (NFPA 1980), the proper heating time-temperature combination needed to attain the desired product sterility can be determined by mathematical calculation of the process time by the "formula method" (Ball 1923, 1928), by inoculated pack studies using organisms of known resistance, or by calculation of microbial lethality by the "general method" (Bigelow *et al.* 1920). Often times, both methods of inoculated pack and calculation based on heat penetration data are used in conjunction with one another to determine the heat process time of a canned food. The formula method is more conducive in determining alternative process times for other combinations of retort temperatures and initial food temperatures.

For the formula method, the temperature of the canned food at the cold spot in the container is measured over time and plotted as log (retort temperature-can temperature) versus time. If this plot exhibits a transformation from one linear section to another, it is designated as a broken line heating curve. A 'break' will typically occur when the physical and/or chemical properties of the food are altered. For example, when heating navy beans, starch leaches from the bean into the brine. Initial brine heating is by convection currents, but the method of heating changes to conduction as the starch content in the brine increases, causing the brine to thicken.

Using the formula method for products exhibiting a broken line heating curve, the process time (B_b) is calculated from the parameters j (representing lag time before the heating curve becomes linear), f_h (slope of the first line), f_2 (slope of the second line), and x_{bh} (time based on the corrected come-up-time and the intersection of the f_h and f_2 lines) (NFPA 1980). Typically, these parameters are calculated from handplotted heating curves, which are thus prone to human error and bias.

By using numerical and statistical methods, this bias can be controlled, since these methods provide results that are uniform and consistent. Examples of numerical methods being applied to heat processing of canned foods include Tung and Garland (1978) applying confidence limits for the process time and least squares to compute the heating factors from the linear section of the heating curve; Patino and Heil (1985) examining the error analysis of the process time determinations to note any uncertainties within the calculations; and Lenz and Lund (1977) employing a Fourier number method to determine the lethality of conduction heating foods.

This study compared various numerical techniques to approximate the heating curve in conjunction with methods to define the location of the 'break' in the broken line heating curve. The process times B_b for the recommended F_o were calculated from the information obtained from these techniques and compared to process times determined from handplotted curves.

MATERIALS AND METHODS

Heat penetration data (i.e., time-temperature measurements) was measured for the following products: navy beans in tomato sauce (303 × 406 can with an Fo = 5.0), red kidney beans in brine (603 × 700 can with an Fo = 8.0), whole white potatoes in brine (303 × 406 can with an Fo = 3.9), and navy beans in brine (303 × 406 can with an Fo = 7). Prior to canning, the beans were soaked for 12–16 h in ambient temperature water, blanched at 212F for 5 min, cooled, placed in the can, brined, and sealed in their respective cans. The white potatoes were sized, peeled, placed in the can, brined, and sealed in the container. To determine the heating characteristics of these products, type T thermocouples had been placed in the cans at the appropriate cold spot (¾ in., 1 in., ¾ in., and ¾ in., respectively) where the cold spots had been previously established. After the products had been sealed in their cans, the cans were placed in the retort, the thermocouples connected to a Doric potentiometer Model 400A, and the steam process started (retort temperature of 240F, 250F, 245F and 250F, respectively). Temperatures were recorded every minute until the temperature inside all cans was 1–2F below the retort temperature. After processing, the cans were placed in ambient temperature water to cool them to 90–110F. For each thermal processing run, the data from nine replicated cans were examined. All data produced broken line heating curves.

Numerical Methods to Approximate Heating Curves

In the following numerical methods, t_i indicates the time at the i^{th} point of N total data points for the given data set; $L(t_i)$, $M(t_i)$, $RF(t_i)$ or $C(t_i)$ is the approximated temperature at t_i for least squares, minmax, rational function, and cubic spline approximations, respectively; and y_i is the actual temperature at time t_i.

Least Squares. The least squares program was prepared using an orthogonalization procedure as outlined by Ralston and Rabinowitz (1978) to produce the polynomial coefficients. In this method, the approximation function L(t) minimizes $\Sigma(L(t_i)-y_i)^2$ for i = 1 to N. For the heating curves, least squares polynomials of degree 2 through 9 were determined for the data points, and the degree polynomial producing

$$\min_{j=2}^{9} \left\{ \max_{i=1}^{N} \left| L_j(t_i)-y_i \right| \right\}$$

was used to establish the heating parameters, where $L_j(t)$ is the approximated polynomial of degree j.

Minmax Approximation. Using the exchange method as shown by Scheid (1968), the minmax polynomial M(t) was approximated by using a set of n points ($n \leqslant N$), where $n-2$ equals the desired degree polynomial. This method minimizes max $|M(t_i)-y_i|$ for every i point of the N total points (called the equal error property); whereas, the function M(t) was determined from just n points. The polynomial of degree 2 to 9 producing the

$$\underset{j=2}{\overset{9}{\text{Min}}} \{ \underset{i=1}{\overset{N}{\text{Max}}} | M_j(t_i)-y_i | \}$$

was used to establish the heating parameters, where $M_j(t)$ is the approximated polynomial of degree j.

Rational Function. The rational function $RF(t) = \{N_o + N_1t + \ldots + n_mt^m\}/\{1 + D_1t + \ldots + D_nt^n\}$ was linearized as stated by Miller (1988), where m and n are the desired degrees of the polynomial for numerator and denominator, respectively, with the maximum value for m and n being 7. The points (t_i, y_i) were substituted in $y = \{N_0 + N_1t + \ldots + N_mt^m\}/\{1 + D_1t + \ldots + D_nt^n\}$; this equation was then linearized to $y^*\{1 + D_1t + \ldots D_nt^n{}_3 = \{N_0 + N_1t + \ldots + N_mt^m\}$ to determine the coefficients $N_0, N_1, N_2, \ldots N_m$ and $D_1, D_2, \ldots D_n$ by Gaussian elimination (Ralston and Rabinowitz 1978)). The rational function producing

$$\underset{n=1}{\overset{7}{\text{Min}}} \{ \underset{m=1}{\overset{7}{\text{Min}}} \{\underset{k=1}{\overset{N}{\text{Max}}} | RF_{m,n}(t_k)-y_k | \}$$

was used to establish the heating parameters, where $RF_{m,n}(t)$ is the approximated rational function with polynomial of degree m in the numerator and degree n in the denominator.

Cubic Spline. The cubic spline $C_i(t)$ for $i = 1$ to $N-1$ was prepared as described by Hamming (1973) where the spline is an approximation that calculates a piecewise, cubic polynomial between each t_i and t_{i+1}. The cubic spline between points must meet the following criteria: $C_i(t_i) = y_i$ for $i = 1$ to $N-1$, $C_{i-1}(t_i) = y_i$ for $i = 2$ to N, $C'_{i-1}(t_i)$ for $i = 2$ to $N-1$, and $C''_{i-1}(t_i) = C''_i(t_i)$ for $i = 2$ to $N-1$. The coefficients of these $N-1$ cubic polynomials were used later to determine the heating parameters.

Establishing Heating Parameters

Ratio Function of Slopes to Determine Break in Curve. To calculate the process time, the heating parameters of f_h, f_2, x_{bh}, and j were needed. The products that we generally processed were those that exhibited an $f_h < f_2$; therefore, when the break in the broken line heating curve occurs, the slope of the curve decreased. (These numerical methods could be utilized for $f_2 < f_h$ with minor alterations.) The location of the break can be determined by taking the ratio of the slopes from two locations on the curve. When the break occurs, this ratio will change from approximately a value of one when taken from a linear area to a value greater than one when taken from the nonlinear area. Graphs with combinations of f_h lines and f_2 lines were presented to several industry personnel who are recognized as thermal processing authorities. The angles of the f_h lines from the horizontal were 30°, 45°, and 60°, and the angle of the f_2 lines from the f_h line were 1°, 2°, 3°, 4°, 5°, 10°, and 15°, where the break in these curves was indicative of slower heating during the f_2 phase of the process. From these curves, the thermal processing authorities indicated that the 2–3° break from the f_h line to the f_2 line denoted a broken line heating curve. Therefore, this 2–3° break was used in this study. Using the cross product for vectors (Swokowski 1983), the slope of f_2 line was determined based on the initial slope of the f_h line with a 2–3° decrease in slope for the f_2 line. Using the cross product, the minimal ratio obtained, where the ratio also had to be greater than one, was 1.09; therefore, this 1.09 value was used as the reference for the minimum ratio of slopes to determine the break in the heating curves based on the numerical equations developed for that data set.

The equations obtained by the previously described numerical methods allow for easy calculation of slopes (which is equivalent to obtaining the first derivative at that point). Using these approximations for the curves, the ratio functions (ratios of slopes) of $S_{10}(i)$ and $S_5(j)$ were compared, where $S_{10}(si)$ = slope of the approximated polynomial at t_i divided by the slope of the approximated polynomial at t_{i+10} for $i = 1$ to $N-10$. $S_5(j)$ was the same ratio as above except that t_{i+10} was replaced by t_{j+5} for $j = 1$ to $N-5$. The break in the heating curve occurred at the time corresponding to t_{I+10} or t_{J+5}, where I corresponds to the i value producing the $\mathrm{Max}(S_{10}(i))$ and J corresponds to the j value producing the $\mathrm{Max}(S_5(j))$, where both the $\mathrm{Max}(S_{10}(i))$ and $\mathrm{Max}(S_5(j))$ must be greater than 1.09.

Since the break in the curve is the transition area where the slopes of the curve decrease, the points for the f_h and f_2 lines were determined slightly removed from this location. The lines f_h and f_2 were determined by linear regression. For the f_2 line, R^2 values (coefficient of determination) were determined for the time intervals from (t_B,t_N), (t_{B+1},t_N),..., (t_{B+5},t_N) where t_B is the time of the break in the curve established from the ratio functions, and the set of points producing the largest R^2 value was used to calculate the f_2 line. To prevent skewing the f_h line by incorporating the initial lag phase, the f_h line was determined by applying linear regression to the time intervals of (t_w,t_x) where $W = 0$ to 5 and $X = B-5$ to B, and the interval producing the largest R^2 value was used to calculate the f_h value. After the f_h and f_2 lines were determined, the x_{bh} value was calculated based on these lines.

Coefficient of Determination to Establish Break in Heating Curve. Besides the ratio method of determining the location of the break, another procedure involved the R^2 which corresponds to the linearity of the data points. For the heating curves, the R_i^2 was calculated for the time intervals of $(t_{N-(10+5\times i)},t_{n-5\times i})$ for $i = 0, 1, 2, \ldots, P$ where P is the greatest whole number such that $P < (N-10)/5$. This data set, which corresponds to an 11 consecutive point sample of the time-temperature data, began at t_N and progressed backward. Then the 11 consecutive points were moved down 5 points to establish the next data set. For example, suppose that the R_0^2 for the first data set corresponded to the temperature points of (t_{30},t_{40}), then the R_1^2 for the next window would correspond to the temperature points of (t_{25},t_{35}). A decrease of the R_i^2 below a specified critical value indicated that the break in the heating curve was occurring. The critical value of R_i^2 was approximately 0.95 but depended on the stability of the time-temperature data obtained for that product. The interval (t_k,t_{k+10}), which produced the minimal R_i^2 value, was utilized to more precisely ascertain the break in the heating curve. The R_m^2 of intervals $(t_{k+3\times m},t_{k+3\times m+6})$ for $m = 0, 1, 2, \ldots, W$ were determined, where W is the greatest whole number such that $W \leqslant (N-6-K)/3$. These intervals corresponded to sets of 7 points to more precisely locate the break in the curve. The break point corresponded to the time $t_{K+3\times m}$, where $M = m$ for min $\{R_m^2\}$. Again, for the f_2 line, R^2 values were determined for the time intervals from (t_B,t_N), (t_{B+1},t_N), ..., (t_{B+5},t_N) where $B = K + 3*M$, which is the index for the break time in the curve as established above, and the set of points producing the largest R^2 value was used to calculate the f_2 line. To prevent skewing the f_h line by incorporating the initial lag phase, the f_h line was determined by applying linear regression to the time intervals of (t_w,t_x) where $W = 0$ to 5 and $X = B-5$ to B, and the interval producing the largest R^2 value was used to calculate the f_h value. After the f_h and f_2 lines were determined, the x_{bh} value was calculated based on these lines.

Graphics to Determine Parameters. A Lotus spreadsheet program was developed to aid in the determination of heating parameters. In this program, the data was graphed appropriately, and the lines for f_h and f_2 were adjusted to the best visual fit using the program. After the best fit had been obtained, the program calculated the j, x_{bh}, f_h, and f_2 values.

Determination of Process Times

For comparison purposes, the data used in the computer programs was hand-plotted, and the processing times were calculated according to Ball's formula assuming that $f_c = f_h$. Using paired t-test at the 5% level (Devore 1987), these process times were statistically compared to the times determined from the hand-plotted data. (Although a statistical comparison of the individual heating factors (j, f_h, f_2, and x_{bh}) may seem warranted, it would be difficult to independently evaluate these results due to the dependent nature of the values of j and x_{bh} on other heating factors of f_h, f_2, and/or corrected come up time. There exists the possibility of comparing the f_h and f_2 values, since these values are determined independently of each other. Normally, the f_h and f_2 lines are determined prior to the calculation of x_{bh}. If different x_{bh} values were used to establish the f_h and f_2 values rather than the procedure of finding f_h and f_2 prior to calculating the x_{bh}, the f_h and f_2 values may be constrained to values that are less than optimal. The "best fit" of the lines to determine the f_h and f_2 lines is critical, especially for the f_2 line, and if these lines are constrained to accommodate a specific x_{bh} value, the process time may be adversely and imprecisely determined. Therefore, to eliminate the problems associated with the dependency and correlation of these heating factors, we compared the process times B_b for different data sets based on the assorted numerical methods to establish the signficance and effectiveness of that method.)

RESULTS AND DISCUSSION

For all data sets, the numerical approximation methods of minmax, least squares, and rational function provided equations that approximated the actual temperatures within 0.001F over the entire data set. [The cubic spline method forces the equation through the points (t_i,y_i); therefore, the difference between approximated and actual temperature was always zero for this method.] When the heating curve demonstrated a gradual curvilinear change rather than the distinctive break typical of the broken line heating curve, all methods developed complications in locating the point of the break. This was not an inherent problem with the numerical method, but with the data since there was no typical distinctive break in the curve.

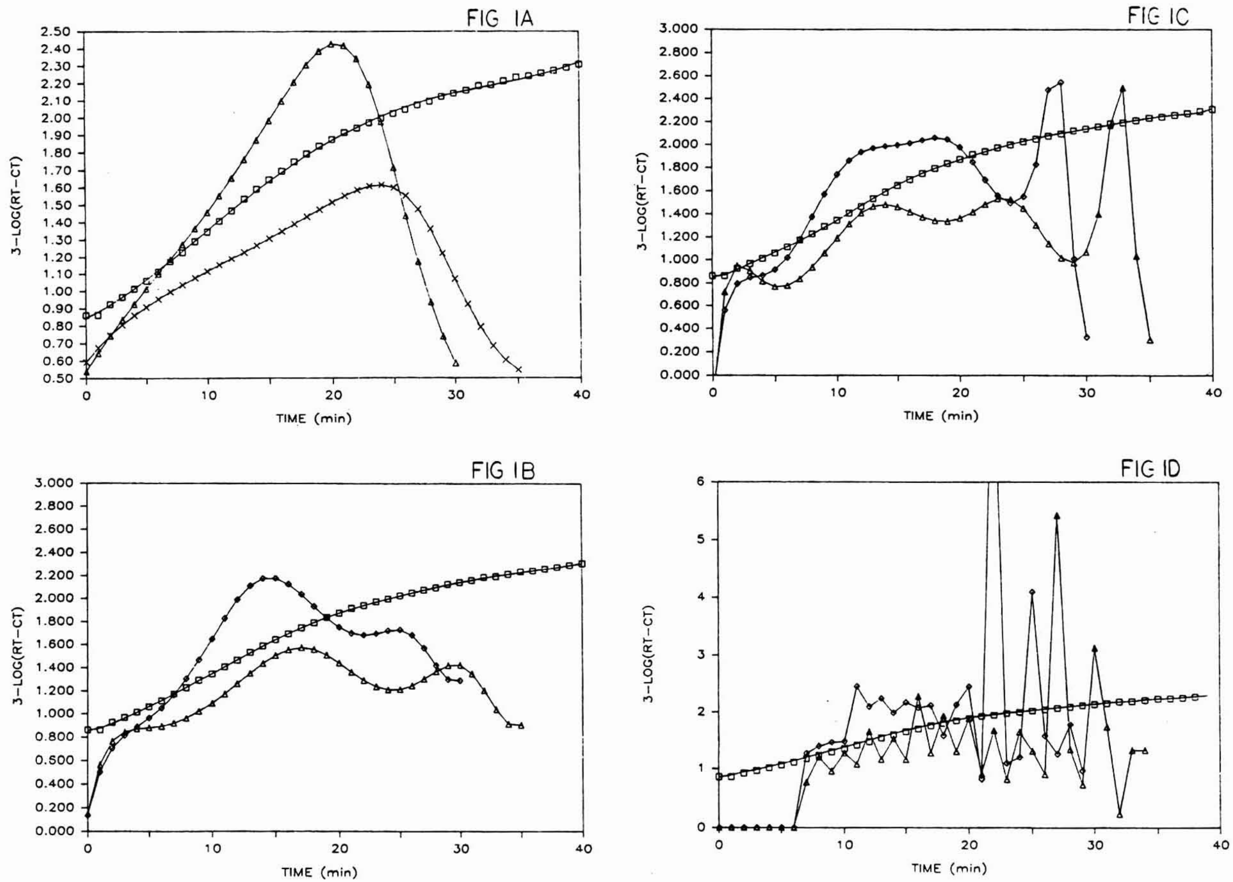

FIG. 1. NUMERICAL APPROXIMATION AND RATIO CURVES FOR THE DATA SET OF NAVY BEANS IN TOMATO SAUCE (303x406 can size) FOR THE FOLLOWING METHODS

A. rational function; B. least squares approximation; C. minmax approximation; D. cubic spline approximation. □ indicate the actual data points with the curve connecting the points being determined by the numerical approximation method. △ and + designate the ratio functions $S_{10}(i)$ and $S_5(j)$, respectively.

For the "coefficient of determination" method, there were difficulties if the time-temperature data was not stable, where stable implies a consistent increase of the log (retort temperature–can temperature) over time for the f_2 portion of the heating curve. Erratic data would generally occur in the later stages of the heat penetration experiment (i.e., near the retort temperature) and may be accounted for by the slight changes in retort temperature due to variations in the steam controller or by thermocouple error due to the small changes in temperature at the end of the process.

The graphs of the approximation functions and ratio functions for navy beans in tomato sauce are shown in Fig. 1. These data are representative of the other data sets. For the rational function (Fig. 1A), the approximation curve and the ratio curves fluctuated less than those for the least squares (Fig. 1B) or minmax approximations (Fig. 1C). For the cubic spline approximation (Fig. 1D), the heating curve approximation was quite smooth, which is one of the beneficial features of this method; however, the ratio curves oscillated excessively. This fluctuation may be explained by the horizontal nature (i.e., slope approaching zero) of the cubic spline curve at the area where the $S_{10}(i)$ or $S_5(j)$ was determined. If the slope ratio were determined in an area where the slope is approaching zero, it would generally cause the ratio to (1) decrease if the numerator were obtained from the more horizontal region or (2) increase if the denominator were obtained from the more horizontal region. For the minmax method, there was an abrupt rise in the curve between t_{N-1} and t_N (Fig. 1C). The slope of the curve in this region was almost horizontal, again implying that any minor fluctuations in the slope would adversely increase the ratio function. Therefore, this was not the location of the 'break,' although this is the region giving the maximum ratio. The occurrence of these fluctuations in the more horizontal areas of the curve causing major changes in the ratio function could occur for minmax, lease squares, cubic spline, or rational function approximations because individual points are being used for slope determinations. If an average of the slopes within an interval of the desired point is obtained, these fluctuations may be minimized. Another possible solution might be to establish a measure of the horizontal character of the curve to serve as an indicator of these difficulties in the slope ratio, thus making the experimenter aware of possible problems in these regions.

For the potato data, the break in the heating curve was not well-defined (Fig. 2). The ratio functions indicated that the break occurred in close proximity to the end of the 40 min heating period which is again due to the horizontal nature of the curve in this area. The same break location for this data was observed for all approximation methods except for the cubic approximation using $S_{10}(I)$, which gave 29 min as the time of the break (Table 1).

Using the break points determined by the ratio function (Table 1) and the coefficient of determination, the process times (Table 2) were calculated and com-

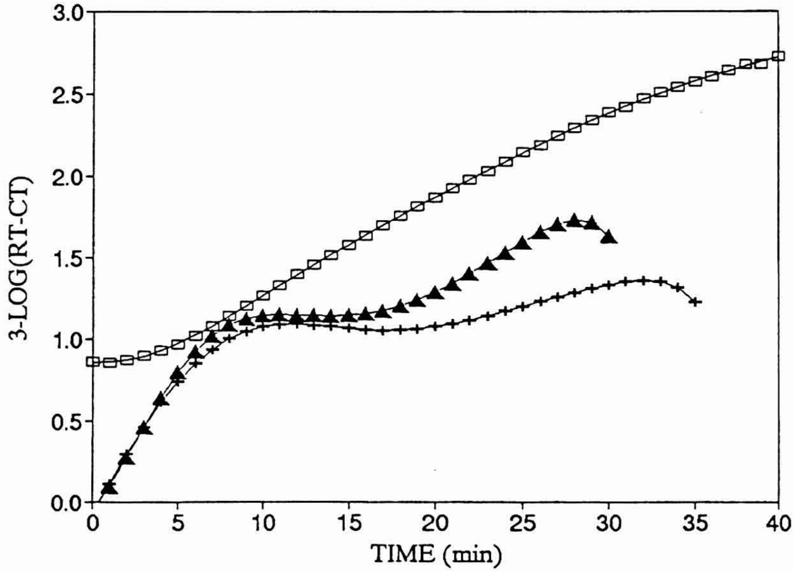

FIG. 2. LEAST SQUARES APPROXIMATION AND RATIO CURVES FOR DATA SET OF WHOLE POTATOES IN BRINE (303x406 can size)
These curves show the gradual change in the heating curve rather than the typical distinctive change associated with a broken line heating curve. □ indicate the actual data point with the curve connecting the points being determined by the numerical approximation method. △ and + designate the ratio functions $S_{10}(i)$ and $S_5(j)$, respectively.

TABLE 1.
DETERMINATION OF 'BREAK' TIME (MINUTES) IN A BROKEN LINE HEATING CURVE FROM THE MAXIMAL VALUE OF RATIOS FUNCTION $R_{10}(I)$ AND $R_5(J)$

	$R_{10}(I)/R_5(J)$			
Approximation method	Navy beans in tomato sauce	Red Kidneys in brine	Whole white potatoes in brine	Navy beans in brine
Least squares	25/22	19/19	38/37	20/17
Minmax	28/29	18/17	36/35	19/16
Cubic spline	32/32	13/18	29/34	17/12
Rational function	25/29	18/17	39/38	19/14

pared to the process times determined from handplotted curves. Using a pairwise comparison, all the calculated process times from the numerical approximation methods were considered to be statistically the same as the process times from the handplotted curves.

TABLE 2.
PROCESS TIMES B_B (IN MINUTES) CORRESPONDING TO THE ABOVE 'BREAK' TIMES AND AS DETERMINED FROM OTHER NUMERICAL METHODS

Approximation method	Navy Beans in Tomato Sauce*	Red Kidney Beans in Brine*	Whole White Potatoes in Brine*	Navy Beans in Brine*
Least squares	30.83/30.79	26.06/26.06	26.05/26.05	31.48/31.41
Minmax	31.71/30.84	26.04/26.76	26.05/26.05	31.48/31.40
Cubic spline	31.04/31.04	26.76/26.00	25.96/26.05	31.98/31.48
Rational function	30.79/31.71	26.04/26.76	26.05/26.05	31.73/31.40
R^2 for break	30.45	26.07	26.12	32.39
Lotus graphics	30.29	25.70	25.42	31.70
Manual graph	29.56	27.13	25.53	30.88
Can Size	303x406	603x700	303x406	303x406
F_o	5.0	8.0	3.9	7.0

* The process times separated by the '/' correspond to the 'breaks' established from the $R_5(J)$ and $R_{10}(I)$ values in Table 1.

In conclusion, the numerical techniques of minmax, least squares, and rational function provide differentiable functions for the times being examined. These numerical techniques used in conjunction with the ratio function provided a plausible approximation to the break in the curve. The cubic spline, which is piecewise differentiable, produces a smooth curve, but there was excessive fluctuation in the slope ratio. However, the spline method did provide reasonable approximations for the break point. Depending on the time-temperature data stability, the "coefficient of determination" method could approximate the break point of the curve. The rational function appeared to provide the best overall approximation of the curve based on differences between actual and approximated temperatures and on the stability of the ratio function. Finally, since the biases and errors of these mathematical/statistical methods are known, the thermal process calculations based on these methods would be more consistent and the possibility of human error/bias would be decreased.

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PREDICTING OPTIMUM MONOSODIUM GLUTAMATE AND SODIUM CHLORIDE CONCENTRATIONS IN CHICKEN BROTH AS AFFECTED BY SPICE ADDITION

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ABSTRACT

Response surface methodology (RSM) was applied to determine the effects of monosodium glutamate (MSG) and sodium chloride (NaCl) concentrations on the hedonic score of nonspiced and spiced chicken broth. Sensory analysis indicated that both MSG and NaCl concentrations affected ($P < 0.005$) the hedonic score of the chicken broth. Estimated by the second order polynomial equation, the maximum hedonic score of nonspiced broth was 7.28 on a 9-point hedonic scale with the combination of 0.33% MSG and 0.83% NaCl. In the presence of spice, the maximum hedonic score increased to 7.81 with the estimated levels of 0.38% MSG and 0.87% NaCl. The increase in the hedonic score of spiced chicken broth might indicate the contribution of spice to the palatability. The increase in levels of MSG and NaCl for the maximum hedonic score of spiced chicken broth was probably due to a masking effect of spices on the taste response of MSG and NaCl.

INTRODUCTION

Sodium chloride (NaCl) is a basic taste modifier and one of the most important nonmeat ingredients in meat and poultry products. It contributes to the flavor of a variety of spices and other flavorings (Mandigo 1991). In general, usage levels of NaCl depends on the type of products and customer preference. It ranges from 0.5% in nugget products to 2.0% in sausage products (Cordray and Huffman 1987), and from 0.75% in canned chicken broth to 1% in canned clear chicken

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noodle soup (Binsted and Devey 1970). According to Trout and Schmidt (1987), there are no legal restrictions on the concentration of NaCl added to meat and poultry products; usually, their effect on flavor is the limiting factor.

Monosodium glutamate (MSG) is the sodium salt of a naturally occurring amino acid, glutamic acid. It is widely used in foods as a flavor enhancer (Solon *et al.* 1985; IFT 1987). In the U.S., MSG has been accepted by the Food and Drug Administration (FDA) as a "Generally Recognized as Safe (GRAS)" substance. Sensory physiologists have suggested that glutamates in foods may provide a fifth basic taste, in addition to sweet, sour, salty, and bitter (IFT 1987). There is an optimal concentration of MSG in food, beyond which the palatability of the food decreases (Yamaguchi and Takahashi 1984a). In a food system, the palatability of MSG varies with the presence of NaCl (Sjostrom and Crocker 1948; Girardot and Peryam 1954; Hanson *et al.* 1960; Yamaguchi and Kimizuka 1979; Yamaguchi and Takahashi 1984b). A level ranging from 0.2 to 0.8% by weight of a food, is recommended to give the best enhancement of the natural food flavor (IFT 1987).

Establishing the proper proportions of ingredients in food products that results in maximum palatability is tedious and expensive. Response surface methodology (RSM) based on a rotatable central composite design permits the researcher to identify the best combination of quantitative variables for an optimum response with a minimum number of experimental combinations (Mullen and Ennis 1979). Also, RSM could be used to determine the effects of treatment combinations within the experimental range (Henika 1982).

The objectives of this study were: (1) to determine the effects of various concentrations of MSG and NaCl on the hedonic score of chicken broth, (2) to optimize the maximum hedonic score with specific treatment combinations, and (3) to compare the effects of spice addition on the hedonic score of chicken broth.

MATERIALS AND METHODS

Experimental Design

A rotatable central composite design (RCCD) as developed by Box and Wilson (1951) was used in this study. The effects of two independent variables (MSG and NaCl concentrations) on a dependent variable (nine-point hedonic scale) of chicken broth were determined. In this study, all nine design points were duplicated for sensory evaluation (Mittal *et al.* 1987). Each panelist was considered as a replicate (Huor *et al.* 1980); therefore, each designed point had 24 observations (12 panelists $\times$ 2 replications). A total of 216 data for 9 designed points were collected. The ranges and intervals of experimental parameters as reported by Yamaguchi and Takahashi (1984b) were adopted.

Preparation of Broth Stock

Broiler breast frames from a hand-deboning operation were obtained from a commercial poultry processing plant and stored at −18C. The frozen breast frames were defrosted at room temperature (25C) for 4 h, excess fat removed, and held in boiling distilled water (1:3 w/w) in covered stainless steel vessels for 3 h. The crude stock was then filtered through four layers of cheesecloth to remove bone fragments and other particles before being further clarified through filter paper (Qualitative P4, Fisher Scientific, Pittsburgh, PA). The filtered broth was chilled at 2–4C overnight. After skimming the fat, the aqueous portion of broth was replenished with distilled water to the original water weight.

Preparation of Nonspiced Broth and Spiced Broth

Pooled broth stock from two cooking batches was divided into two parts. One part was used for preparation of the nonspiced broth (control) by adding the indicated amounts of MSG and NaCl levels (Table 1). The other part was used

TABLE 1.

ACTUAL AND CODED LEVELS OF MSG AND NaCl USED IN A ROTATABLE CENTRAL COMPOSITE DESIGN

Treatment number	Actual levels (%)		Coded levels	
	MSG	NaCl	MSG[1]	NaCl[2]
1	0.50	0.80	+1.414	0
2	0.43	1.08	+1	+1
3	0.25	1.20	0	+1.414
4	0.07	1.08	-1	+1
5	0	0.80	-1.414	0
6	0.07	0.52	-1	-1
7	0.25	0.40	0	-1.414
8	0.43	0.52	+1	-1
9	0.25	0.80	0	0

[1] Coded level = (Actual level - 0.25) / 0.18

[2] Coded level = (Actual level - 0.80) / 0.28

for preparation of spiced broth by the following procedures. After preparing the spiced broth by adding 0.125% granulated onion (Ralph's Food Co., Corpus Christi, TX), 0.0125% garlic powder (Kroger Co., Cincinnati, OH), 0.0125% ground white pepper (Kraft Inc., Glenview, IL), and 0.0125% whole celery seed (McCormick & Co., Baltimore, MD), each spiced broth stock was reheated to 90C, held for 1 h, and then filtered through four layers of cheese cloth to remove the spice residues. This filtered broth stock was further processed by adding MSG and NaCl as indicated in Table 1. Both nonspiced and spiced broths were stored in a refrigerator (2–4C) and sensory evaluated within four days. This spiced chicken broth formulary was developed in our laboratory. The canned condensed chicken broth formulary (Komarik *et al.* 1974) was used as a reference during our broth formulary development work.

Sensory Evaluation

Sensory evaluations were conducted by 12 experienced panelists. In panelist selection, triangle tests were used for screening candidates. The method as described by Cross *et al.* (1978) was adopted to train the panelists after selection of panel members.

Sensory evaluation was conducted at 3:00 p.m. for four days. All test samples were warmed to approximately 60C using a microwave oven and served to panel members in plastic cups identified with three randomly coded numbers. A hedonic scale scoring system ranging from 1 = "dislike extremely" to 9 = "like extremely" was used to rank the preference of test samples (Larmond 1977). Panelists were asked to evaluate test samples at random. Tap water was used between samples to cleanse the palate.

Statistical Analysis

Experimental data were analyzed by the response surface regression procedure (PROC RSREG) of the Statistical Analysis System (SAS) computer package (SAS/STAT 1988). The following quadratic polynomial equation was used to fit the second-order response surface (Box and Behnken 1960; John 1971; Montgomery 1984; Petersen 1985; Box and Draper 1987; Likimani *et al.* 1991).

$$E(y) = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

A three-dimensional response surface was created from a quadratic equation using the three-dimensional graph procedure (PROC G3D) of SAS (SAS/GRAPH 1988). Contour plots were generated from a quadratic equation using the Plot Procedure (PROC PLOT) of SAS (SAS/GRAPH 1988). Superimposing contour diagrams were carried out to visually determine the effects of spice addition on the hedonic scores as a function of MSG and NaCl.

RESULTS AND DISCUSSION

Model Fitting

The mean hedonic scores and the corresponding values predicted by the fitted equation for each of the treatment combinations of nonspiced and spiced broths are presented in Table 2. In general, there is a close agreement between the mean hedonic score and the predicted value at each treatment combination. The ANOVA (Table 3) showed the adequacy and fitness of model (lack of fit) was not significant ($P > 0.05$) for nonspiced or spiced broth system. These results indicated

TABLE 2.

MEAN HEDONIC SCORES AND PREDICTED VALUES OF NONSPICED AND SPICED CHICKEN BROTHS IN A CENTRAL COMPOSITE DESIGN

	Nonspiced broth		Spiced broth	
Trt.[1]	Experimental values[2]	Predicted values[3]	Experimental values[2]	Predicted values[3]
	Mean Values ± Standard Deviation		Mean Values ± Standard Deviation	
1	6.88 ± 0.85	6.84	7.75 ± 1.03	7.53
2	6.08 ± 1.32	6.05	6.88 ± 1.36	7.00
3	5.00 ± 0.88	5.09	5.88 ± 1.62	5.91
4	5.58 ± 0.83	5.47	6.04 ± 1.20	5.88
5	5.54 ± 0.88	5.63	5.21 ± 1.41	5.40
6	4.58 ± 1.06	4.56	3.83 ± 1.24	3.74
7	4.25 ± 1.19	4.21	3.50 ± 1.56	3.44
8	5.67 ± 1.17	5.73	5.50 ± 1.35	5.69
9	7.17 ± 0.87	7.17	7.42 ± 0.93	7.42

[1] Trt. = Treatment; the levels of MSG and NaCl used for treatment combinations according to TABLE 1.

[2] Experimental values were an average of 24 results.

[3] Predicted values were calculated from the fitted equation.

$$E(y) = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

that the two fitted models adequately represented the data (Myers 1971; Montgomery 1984; Petersen 1985).

The coefficients of determination (R^2) were 0.45 and 0.53 for nonspiced and spiced broth models, respectively (Table 3). The low R^2 indicated that the regression model did not account for all of the variations observed (Nelson and Hsu 1985). In other words, other factors are also partially responsible for the variations.

Effects of MSG and NaCl on Nonspiced Broth

The ANOVA for the nonspiced broth model (Table 3) revealed the quadratic effect was highly significant ($P < 0.005$), but the cross-product effect was not significant ($P > 0.05$). The three-dimensional surface response of nonspiced broth as a function of MSG and NaCl is illustrated in Fig. 1(a). The hedonic scores

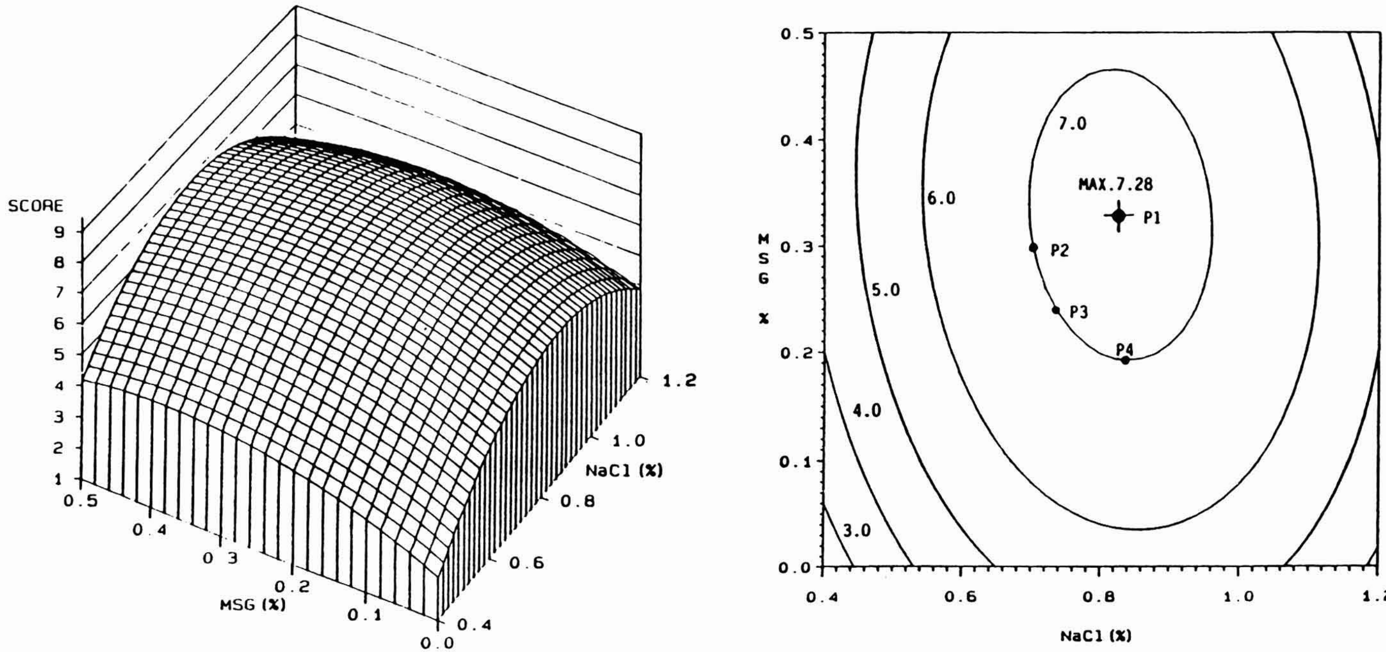
TABLE 3.

ANALYSIS OF VARIANCE FOR THE EFFECT OF MSG AND NaCl CONCENTRATION AS A LINEAR TERM, QUADRATIC TERM AND INTERACTIONS (CROSS-PRODUCT)

Regression	Degree of freedom	Sums of squares	
		Nonspiced broth	Spiced broth
Model	5	179.70***	409.29***
Linear	2	54.43***	255.58***
Quadratic	2	123.23***	149.54***
Cross-Product	1	2.04	4.17
Residual	210	216.13	364.04
Lack of fit	3	0.88 ns	4.21 ns
Pure error	207	215.25	359.83
Total	215	395.83	773.33
R-square		0.45	0.53

*** Significant at the 0.5 % level of probability.

ns No significance at the 5% level of probability.



(a) RESPONSE SURFACE

(b) CONTOUR DIAGRAM

FIG. 1. RESPONSE SURFACE AND CONTOUR DIAGRAM OF THE HEDONIC SCORE OF NONSPICED CHICKEN BROTH AS A FUNCTION OF MSG AND NaCl LEVELS

increased with increasing MSG levels to a peak and then tended to decrease as the level of MSG increased regardless of various designed NaCl additions. Results also indicated that increased NaCl levels at various MSG levels had a similar effect on the hedonic scores. These data tended to agree with Yamaguchi and Takahashi (1984a) who reported there was an optimal level of MSG in food systems and beyond this level, the palatability of the food decreased. Also, Trout and Schmidt (1987) reported the flavor of meat and poultry products increased to a maximum at an optimal NaCl level and then decreased at higher concentrations.

The ANOVA of the independent variables (Table 4) showed that both MSG and NaCl concentrations were important ($P < 0.005$) for the hedonic score of broths. The regression coefficients based on the fitted equation are presented in Table 5. The coefficients of the quadratic effect (b_{11} for MSG and b_{22} for NaCl) were highly significant ($P < 0.005$).

A contour plot of the constant hedonic scores as a function of MSG and NaCl concentrations for nonspiced broth is shown in Fig. 1(b). The maximum hedonic score, 7.25 (near "like moderately"), was obtained at a combination of 0.33% MSG and 0.83% NaCl (P_1). It is possible that various combinations of MSG and NaCl concentrations had the same hedonic score. As shown in Fig. 1(b), the minimum level of NaCl added for a predicted hedonic score of 7.0, was 0.70% with 0.30% MSG (P_2). A further decrease in MSG concentration (0.24%) was necessary for a increased NaCl concentration to 0.74% in maintaining a same hedonic score of 7.0 (P_3). On the other hand, the minimum level of MSG added at a predicted hedonic score of 7.0 was 0.19% with 0.84% NaCl (P_4). At a lower

TABLE 4.

ANALYSIS OF VARIANCE FOR THE EFFECTS OF MSG AND NaCl CONCENTRATIONS ON THE HEDONIC SCORES OF NONSPICED AND SPICED CHICKEN BROTHS

Factor	Degree of freedom	Sums of squares	
		Nonspiced broth	Spiced broth
Concentration of MSG (%)	3	53.34***	131.30***
Concentration of NaCl (%)	3	130.94***	280.40***

*** Significant at the 0.5 % level of probability.

TABLE 5.

REGRESSION COEFFICIENTS OF THE SECOND ORDER POLYNOMIALS FOR NONSPICED AND SPICED CHICKEN BROTHS

Coefficients[1]	Nonspiced broth	Spiced broth
b_0	-5.89***	-8.87***
b_1	12.18***	15.20***
b_2	26.96***	31.56***
b_{11}	-14.87***	-15.26***
b_{22}	-15.71***	-17.15***
b_{12}	-2.89	-4.13

1 Estimated according to a second degree polynomial model as following:

$$E(y) = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

*** Significant at the 0.5 % level of probability.

NaCl concentration (0.74%), an increase in MSG concentration (0.24%) was required to keep the same score (P_3). Yamaguchi and Takahashi (1984b) studied the interaction of MSG and NaCl on palatability of a traditional Japanese clear soup (sumashi-jiru) and indicated that more NaCl was required in the soup with lower MSG for maximum palatability, and vice versa.

The sodium ion contents of MSG and NaCl are 12.3% and 39.3%, respectively (Yamaguchi and Takahashi 1984b). Comparison of MSG and NaCl levels in point P_2 and P_4 [Fig. 1(b)], suggests that a MSG and NaCl combination at P_2 (0.70% NaCl and 0.30% MSG) was more suitable than P_4 (0.84% NaCl and 0.19% MSG) for the formulation of chicken broth with lower sodium ion content at a predicted hedonic score of 7.0.

Effects of MSG and NaCl on Spiced Broth

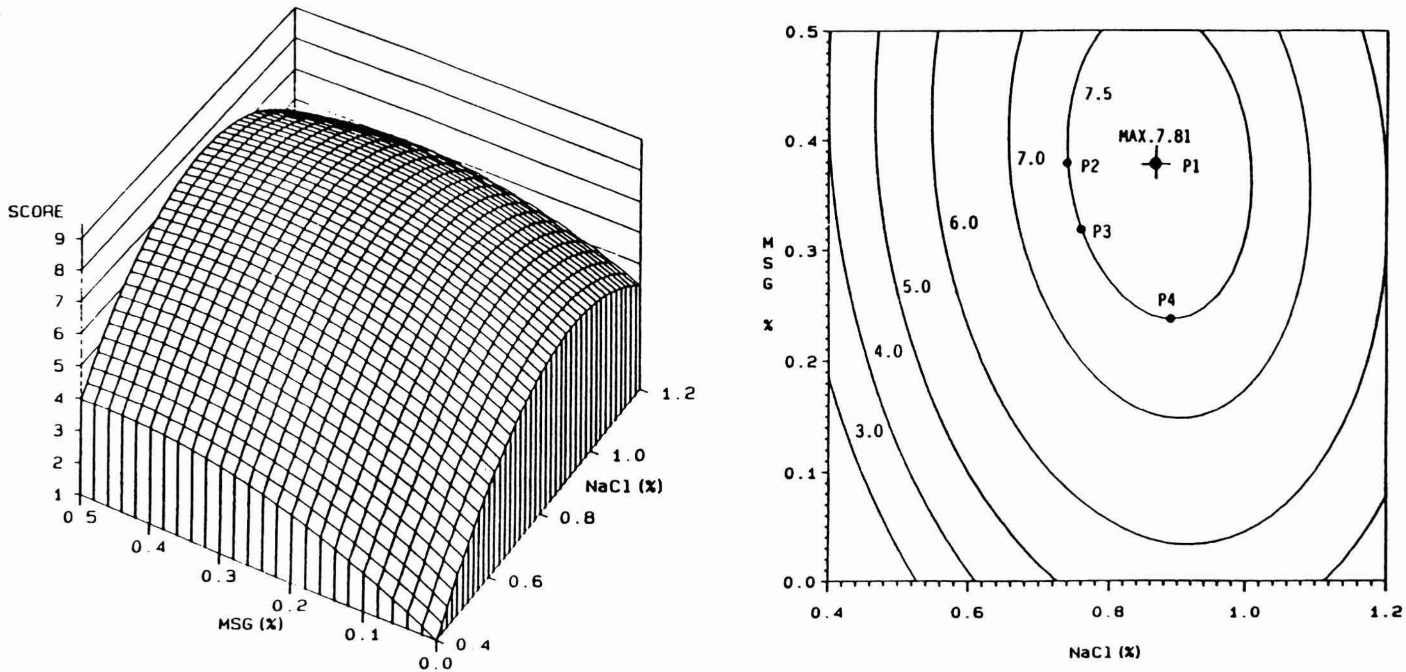
In general, the effects of MSG and NaCl on the spiced broth system were similar to the results of the nonspiced broth system. The quadratic effects of MSG and NaCl were highly significant ($P < 0.005$), but the cross-product effect was not significant ($P > 0.05$) (Table 3). Both MSG and NaCl concentrations were important factors ($P < 0.005$) affecting the hedonic scores of broth (Table 4). The regression coefficients also indicated that both MSG and NaCl had quadratic effects ($P < 0.005$) (Table 5).

The three-dimensional surface response of the hedonic score of spiced broth is illustrated in Fig. 2(a). The hedonic scores increased with increasing MSG or NaCl concentrations at low levels; however, further increasing their concentrations decreased the hedonic scores. A contour diagram of hedonic scores of spiced broth is shown in Fig. 2(b). The maximum hedonic score, 7.81 (near "like very much"), was estimated at a combination of .038% MSG and 0.87% NaCl (P_1). The minimum level of added NaCl at 7.5 hedonic score was 0.74% with 0.38% MSG (P_2). As we further decrease the MSG concentration to 0.32%, it is necessary to increase NaCl level to 0.76% in order to maintain the same hedonic score of 7.5 (P_3). On the contrary, the minimum level of MSG added at a score of 7.5 was 0.24% with 0.89% NaCl (P_4). Further decreasing the NaCl level (0.76%) required an increase in MSG level (0.32%) to maintain the same hedonic score (P_3). These relationships were similar to those obtained from the nonspiced broth system.

Effects of Spice Addition on Chicken Broth

Superimposing Fig. 1(b) and 2(b) demonstrates that the hedonic scores of chicken broth were affected by spice addition (Fig. 3). The hedonic scores of spiced broth on the left side of the AB line (Fig. 3) had lower values than those of the nonspiced. For example, the spiced broth at the combination of 0.20% MSG and 0.62% NaCl levels had the hedonic score of 6.0 (P_1), while, at the same levels of MSG and NaCl, the nonspiced broth had a hedonic score greater than 6.0 (P_1). On the other hand, the nonspiced broth with 0.20% MSG and 0.58% NaCl addition had a hedonic score of 6.0)P_2). If we want to hold the same hedonic score (6.0) for spiced broth and maintain the same level of MSG addition (0.20%), the NaCl level needed to be increased to 0.62% (P_1). In addition, increasing the MSG from 0.20% to 0.26% and retaining the NaCl level at 0.58% also resulted in a 6.0 score for spiced broth (P_3). These observations might be due to the masking effect of spice on taste response to MSG and NaCl.

The spiced broth at treatment combinations of MSG and NaCl levels on the right side of the AB line (Fig. 3) had higher hedonic scores than those of the nonspiced broth. For example, the spiced broth at a 0.20% MSG and 0.76% NaCl combination had a predicted hedonic value of 7.0 (P_4), while lower than 7.0 was predicted for the nonspiced broth at the same MSG and NaCl levels (P_4). These results indicated the masking effect of spice addition might not be large enough to affect the hedonic score of spiced broth in these combinations of MSG and NaCl levels.



(a) RESPONSE SURFACE

(b) CONTOUR DIAGRAM

FIG. 2. RESPONSE SURFACE AND CONTOUR DIAGRAM OF THE HEDONIC SCORE OF SPICED CHICKEN BROTH AS A FUNCTION OF MSG AND NaCl LEVELS

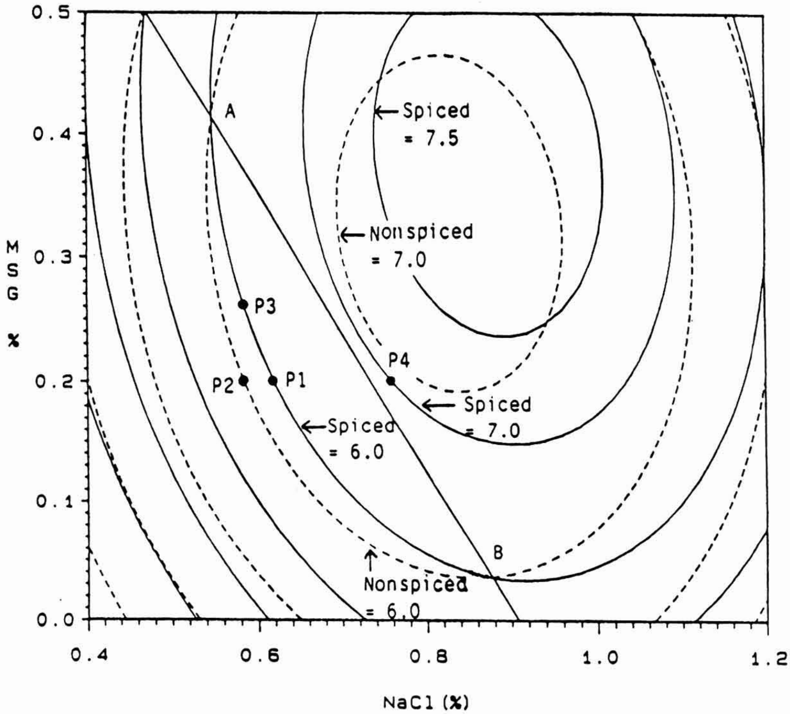


FIG. 3. SUPERIMPOSING CONTOUR DIAGRAMS OF THE HEDONIC SCORES OF NONSPICED (— —) AND SPICED (——) CHICKEN BROTHS AS A FUNCTION OF MSG AND NaCl LEVELS

When comparing the maximum predicted hedonic scores, the spiced broth had a higher value (7.81, near "like very much") than nonspiced broth (7.28, near "like moderately"). The increase in the maximum predicated hedonic score indicated that the spice contributed to the taste response and improved the palatability at the optimum condition.

CONCLUSION

The effects of MSG and NaCl on the hedonic score of nonspiced and spiced chicken broths were highly significant ($P < 0.005$). An increase of MSG and NaCl levels had a quadratic effect ($P < 0.005$) on the hedonic score of the broth. Spiced broth had a higher maximum hedonic score, 7.81 (near to like very much), than nonspiced broth, 7.28 (near to like moderately). This result indicated that the spice might contribute to the hedonic score, as did MSG and NaCl. In general, the spiced broths with low MSG and NaCl levels had lower hedonic scores than the nonspiced. This is probably due to the taste masking effect of the spice. Conversely, the spiced broth with high MSG and NaCl levels had higher hedonic scores than the nonspiced. The levels of MSG and NaCl for the maximum hedonic score of nonspiced broth were estimated at 0.33% and 0.83%, respectively. The MSG and NaCl levels for the maximum hedonic score of spiced broth increased to 0.38% and 0.87%, respectively. In addition, it is possible to maintain the hedonic score of chicken broth at the same level by reducing the addition of NaCl with increased presence of MSG.

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EFFECT OF EXTRUSION VARIABLES ON THE PHYSICAL CHARACTERISTICS OF RED BEAN (*PHASEOLIS VULGARIS*) FLOUR EXTRUDATES

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ABSTRACT

Red bean flours containing either low or high moisture were extruded at dough temperatures of either 90, 110, or 124C at screw speeds of either 80, 120, or 160 rpm in a Brabender Model PL-V500 single screw laboratory extruder. Resulting extruder torque and extrudate yield, expansion, density, breaking strength, and water absorption and solubility indices were measured. Moisture significantly ($P \leqslant 0.01$) influenced torque, expansion, while temperature significantly influenced torque, expansion, breaking strength and water absorption index. Screw rpm only influenced yield.

INTRODUCTION

For most of the Caribbean Islands and in Central America, different varieties of beans (*Phaseolis vulgaris*), along with the cereals corn, rice, and millets, constitute the staple foods.

Traditional bean cooking results in both high energy input and time consumption. More convenient ways of cooking or an adequate precooked product would be very useful for the consumers in these countries. In addition, many studies

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have attempted to solve the hardness problem in stored beans and the resulting long time necessary for bean preparation. Unfortunately, length of cooking time for whole beans after a few months of storage is still an unsolved problem. Therefore, it would be useful to investigate other processes applicable to the cooking of beans.

A potential alternative to traditional cooking is extrusion cooking. This method offers numerous advantages including versatility, high productivity, low operating cost, energy efficiency, high quality of resulting products with a minimum degradation of nutrients and an improvement in digestibility and biological value (Harper 1981).

Several studies (Aguilara *et al.* 1984; Jennick and Cheftel 1979; Pham and Del Rosario 1984) have been carried out on the extrusion of different varieties of beans, either alone or in combination with other ingredients, but these studies were mainly oriented towards investigating the nutritional and biological effects of the extrusion process. A better understanding of the physical behaviors of dry beans during extrusion would be very useful for the planning and production of convenient new foods from beans.

The present study was conducted to study the effects of process variables (such as extrusion temperature, feed moisture content, and screw velocity during extrusion cooking) on the physical characteristics of extrudates from dry red bean flour, a staple food of the Caribbean Basin.

MATERIALS AND METHODS

Methods

Commercially available dry red beans (*Phaseolis vulgaris*) grown on irrigated land in Eastern Colorado were obtained. They had been cleaned and commercially stored at ambient temperatures for approximately six months before they were ground to pass through a 2 mm screen using a Model No. 4 laboratory Wiley Mill.

Conditioning

The moisture content of the resulting red bean flour was determined and adequate quantities of room temperature tap water were added to obtain either 15 or 25% wet weight total moistures. The moistened flours were blended for 20 min with a wire whip in a Model No. 20 Hobart mixer at a speed setting of two. The resulting products were permitted to stabilize for 2 h at room temperature in sealed plastic bags.

Extrusion

All runs were performed on a Brabender Model PL-V500 laboratory extruder having a 19.05 mm barrel diameter, a 20:1 length to diameter ratio, eight 0.29 × 3.18 mm longitudinal grooves and a die plate equipped with a 4.5 mm diameter die opening. The barrel was equipped with two electrically heated collars cooled with compressed air and thermostatically controlled to ± 2C. The extruder was equipped with a variable speed drive, a tachometer, and a balanced type torque indicator. A 3:1 compression screw was used and the unit operated under steady state conditions to obtain dough temperatures just before the die of either 90, 110, or 134C at screw speeds of either 80, 120, or 160 rpm. Resulting extrudates were permitted to cool and dry at room temperature overnight.

Measurements

Torque values were read directly from the torque indicator. Yield was measured by collecting 1-min samples followed by weighing after overnight room temperature storage and the results expressed a kg/h. The radial expansion, which is the ratio of the mean cross-sectional diameter of the extrudate to the die exit diameter, was manually measured and calculated as a ratio. Extrudate breaking strength was measured using a Warner-Bratzler shear press with the pounds of force required to break the extruate converted to kg. Product density was determined by measuring the displacement of rapeseed in cc/gram of sample using a graduated cylinder. Water abortion index (WAI) and water solubility index (WSI) were measured using the method described by Anderson *et al.* (1970). All measurements were performed in triplicate on three random samples from each variable on two sets of samples extruded on two consecutive days.

Experimental Design and Statistical Analysis

A full factorial design using the SPSSX statistical package was utilized with dough temperature, feed moisture, and screw speed designated as independent variables.

RESULTS AND DISCUSSION

Red bean extrudates had two distinct appearances dependent upon feed moisture content. Products extruded at high moisture (25%) were less expanded and more colored but nonhomogenous in appearance, whereas the lower moisture (15%) feeds produced extrudates that had a more uniform appearance and were more expanded. Expansion results under optimum temperature and moisture condition, whereas color formation is more influenced by temperature and appropriate precursors required for the Maillard reaction.

Table 1 summarizes the overall statistical analysis of this study. It can be seen that from the three process variables evaluated, feed moisture and extrusion temperature had a very significant effect ($p \leqslant 0.01$) on most of the dependent variables, while rpm only significantly influenced extrudate yield. None of the three process variables had any significant effects upon extrudate densities and water solubility indices.

Torque

As can be seen in Fig. 1, torque was influenced by product moisture and extrusion temperature, with both increased moisture and temperature causing a decrease in torque. It is logical that an increase in moisture will decrease torque by diluting bean starch, thus producing a more flowable product. Similar results have been reported by Kin and Maga (1987). Lower torque in turn will result in lower power requirements, thereby lowering the cost to reprocess such a product.

The influence of temperature on torque can be explained by the fact that dough consistency becomes thinner as temperature increases, thereby making it easier for the product to flow through the extruder. Overall, extruder rpm did not have a significant influence of torque, with torque values being fairly constant at 80 and 120 rpm. However, when comparing 120 and 160 rpm, it can be seen that some variables caused a slight but not significant increase or decrease in torque.

TABLE 1.

STATISTICAL ANALYSIS USING SPSSX: EFFECT OF FEED MOISTURE, EXTRUSION TEMPERATURE, AND RPM ON THE PHYSICAL CHARACTERISTICS OF RED BEAN EXTRUDATES

Variable	Torque	Yield	Expansion	Breakability	WAI	WSI	Density
Moisture	**	**	**	**	NS	NS	NS
Temperature	*	NS	**	**	**	NS	NS
RPM	NS	**	NS	NS	NS	NS	NS
Moisture x Temp.	NS	NS	NS	NS	NS	NS	NS
Moisture x RPM	NS	NS	NS	NS	NS	NS	NS
Temp. x RPM	NS	NS	NS	NS	NS	NS	NS

*: Significant at the 0.05% level.
**: Significant at the 0.01% level.
NS: Not significant.

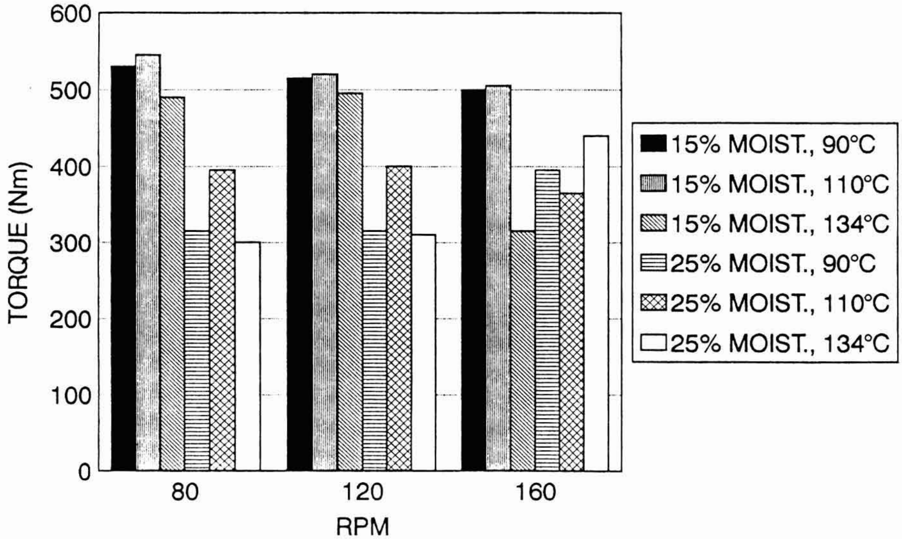

FIG. 1. INFLUENCE OF FEED MOISTURE (%), DOUGH TEMPERATURE (C), AND EXTRUDER RPM ON RESULTING TORQUE

Yield

Yield represents another important economic parameter since it influences production capacity. The influences of feed moisture, extrusion temperature, and rpm are summarized in Fig. 2, where it can be seen that the lower moisture (15%) variables had significantly higher yields than high moisture (25%) feed materials. It must be remembered that yield was measured after the extrudates had air dried, and thus extrudates that were originally formulated with 25% moisture, dried to approximately the same final moisture level as samples extruded with 15% moisture, thus resulting in overall lower yields. It is logical that yield increased as rpm increased since this resulted in greater throughput. Statistically, no differences were noted in yield relative to extrusion temperatures evaluated in this study.

Expansion

Extrudate expansions was significantly influenced by both feed moisture and extrusion temperature (Fig. 3). These two variables counteracted each other because increasing the extrusion temperature increased expansion, whereas increasing the feed moisture content from 15 to 25% decreased extrudate expansion. As temperature increased, more of the starch was fully cooked and thus

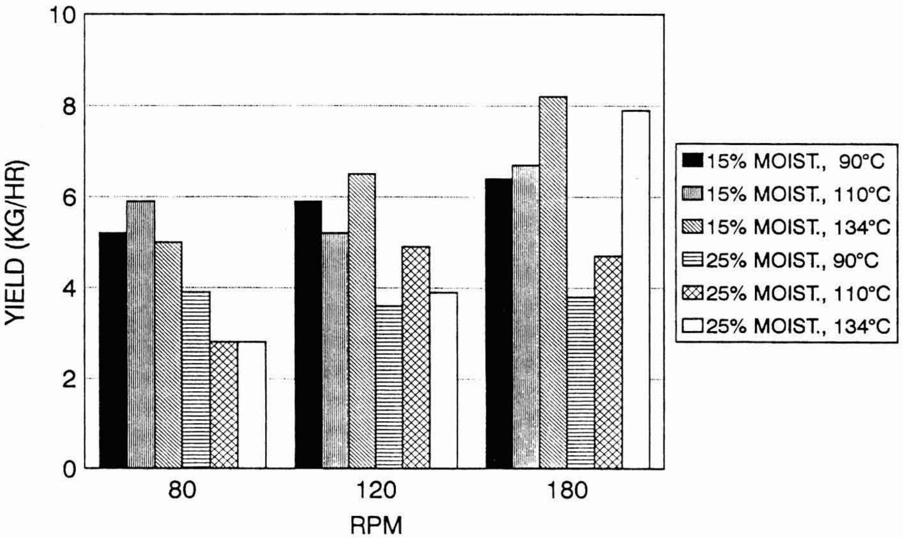

FIG. 2. INFLUENCE OF FEED MOISTURE (%), DOUGH TEMPERATURE (C), AND EXTRUDER RPM ON RESULTING EXTRUDATE YIELD

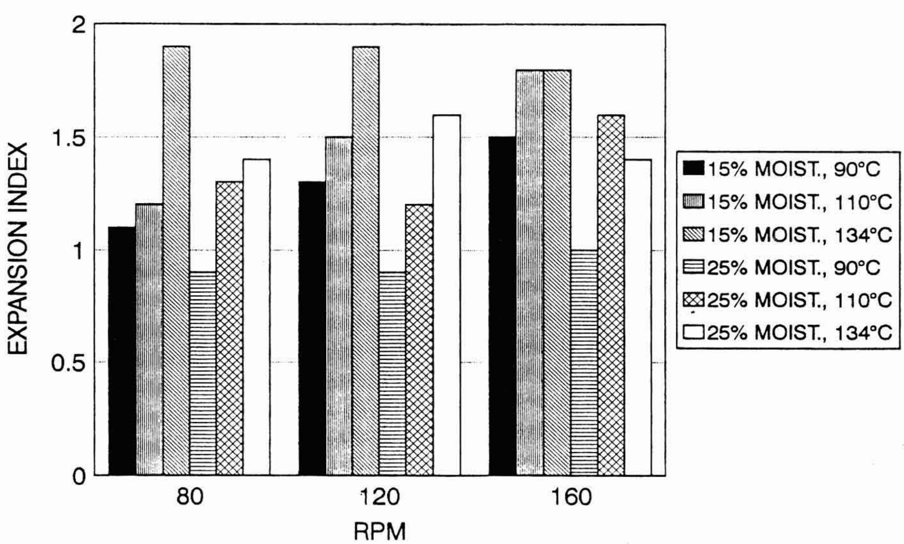

FIG. 3. INFLUENCE OF FEED MOISTURE (%), DOUGH TEMPERATURE (C), AND EXTRUDER RPM ON RESULTING EXTRUDATE EXPANSION INDEX

better able to participate in expansion. However, an increase in moisture tended to slow down the cooking process due to the relatively short retention time, thereby limiting extrudate expansion. Other groups have found similar relationships with other feed materials (Kim and Maga 1987; Kim *et al.* 1989). RPM was found not to significantly influence expansion.

Breaking Strength

Feed moisture and extrusion temperature were also found to significantly influence extrudate breaking strength (Fig. 4). As can be seen, a wide range in breaking strength was observed. This in turn would influence grinding properties if the resulting extrudates were to be ground into a precooked flour. Products made from 15% feed moisture had a lower breaking strength than extrudates made from high moisture feeds. Extrudates made from low moisture feed were more completely cooked, which in turn lowered structural strength. Also, breaking strength decreased with an increase in extrusion temperature, thereby demonstrating that as the product became more cooked, its structure became more fragile and thus easier to beak. Overall, rpm did not have s significant influence on breaking strength, especially when comparing 80 and 160 rpm. However, breakability increased or decreased at 120 rpm, dependent upon the variable.

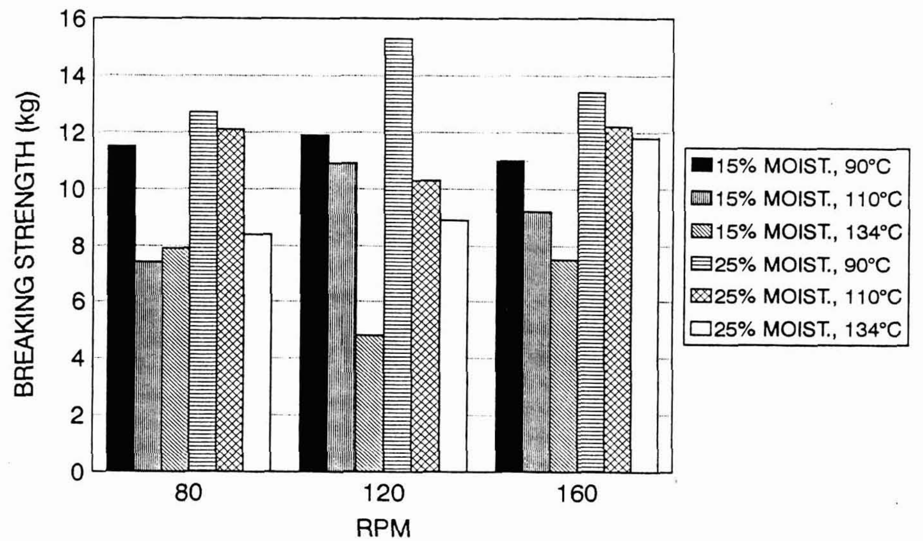

FIG. 4. INFLUENCE OF FEED MOISTURE (%), DOUGH TEMPERATURE (C), AND EXTRUDER RPM ON RESULTING EXTRUDATE BREAKING STRENGTH

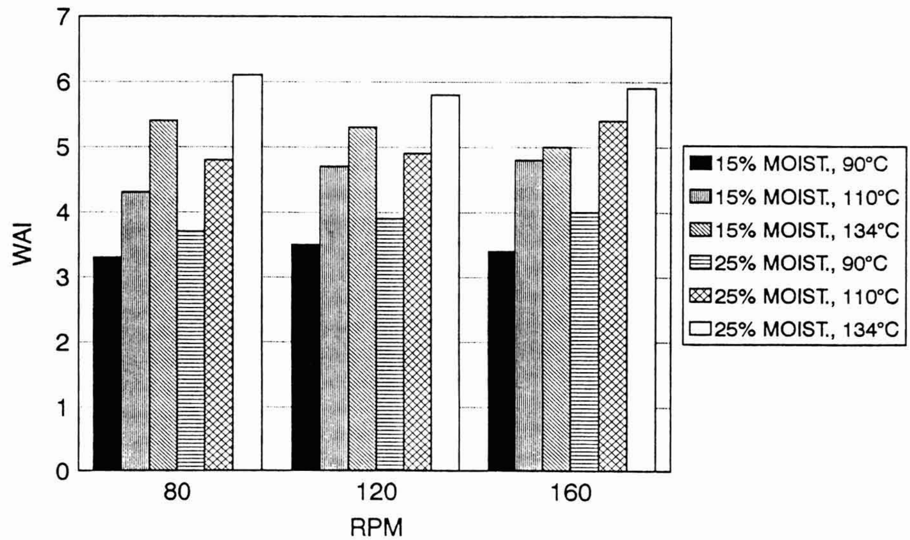

FIG. 5. INFLUENCE OF FEED MOISTURE (%), DOUGH TEMPERATURE (C), AND EXTRUDER RPM ON RESULTING EXTRUDATE WATER ABSORPTION INDEX (WAI)

Water Absorption Index

Extrusion temperature was the only variable shown to significantly influence water absorption index. Since this measurement can serve as an index of product functionality (Maga 1976), it is important to obtain a maximum value. As seen in Fig. 5, water absorption index increased with extrusion temperature. Other studies have reported similar results with other ingredients (Anderson *et al.* 1970; Aguilera and Kosikowski 1978; Kim and Maga 1987; Pham and Del Rosario 1984).

Density and Water Soluble Index

Under the conditions evaluated, density and water solubility index were not significantly influenced by any of the variables considered. Other research (Tribelhorn *et al.* 1986) reported that low moisture feed increased extrudate solubility.

CONCLUSIONS

Feed moisture and extrusion temperature were found to be the variables most influential in modifying the physical properties of extruded red beans. Screw rpm only influences extrudate yield. In most instances, changing the variables resulted in extrudates that had vastly different physical properties. Therefore, one set of conditions could be used to produce a more dense and hard product, whereas another set of conditions could be utilized to yield an expanded product.

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EFFECT OF METAL SHIELDING ON MICROWAVE HEATING UNIFORMITY OF A CYLINDRICAL FOOD MODEL

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ABSTRACT

Cylindrical model food samples containing 3% agar gel were shielded with metal bands during microwave heating. The metal bands were arranged in various patterns, with different spacing and orientation. The focus of this work was to study how these patterns could affect the heating uniformity and power absorption in the samples. The heating rates of the samples during microwaving were measured with fiberoptic temperature sensors. A two-factor central composite rotatable design and the corresponding response surface methodology were used to analyze the data. It was found that orientation was an important design parameter, and it was possible to design patterns that could greatly increase the heating uniformity without greatly reducing the power absorption.

INTRODUCTION

Microwave reheating of foods has become an integral part of our life. Today more than 80% of the United States households own at least one microwave oven (Anon. 1991), and more than a thousand microwaveable food products are available in the market. For example, a popular package type is the high barrier, shelf-stable, semi-rigid plastic container (Spaulding 1987).

Obviously, microwaveable food products have a bright future, but they also present many technical challenges. A major problem is related to uneven heating, which causes hot and cold spots in the food, during microwaving (Schiffmann

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1981; Carlin *et al.* 1982; Lingle 1987). In general, there are several possible means to minimize the uneven heating: through design of the microwave oven, ingredient formulation, design of the package, or a combination of these.

Microwaves are electromagnetic waves consisting of an electrical and a magnetic component. Similar to light, microwaves can be transmitted, reflected or absorbed when interacting with materials. It is well-known that metal foil can be used as reflectors to protect microwave sensitive food areas from over-processing or over-reheating, and contrary to common belief, metal can be safely (without arcing) used as part of microwaveable package if the package is carefully designed (such as avoiding sharp corners). Decareau (1978) found that placing an aluminum foil container inside microwave oven did not damage the magnetron. Kashyap and Wyslouzil (1980) observed no noticeable effect on microwave heating of materials due to the presence of metallic objects, such as pie plates, metal-capped jars, and metal racks. Wirth (1988) reported that using aluminum foil trays had no adverse effects on microwave ovens manufactured after 1980. Chou (1984) and Narui (1985) reported that plastic sheets containing discontinuous aluminum coating (manufactured by vacuum deposition and stretching the sheets) exhibited no spark formation during microwaving.

Although there are some published scientific papers related to microwave heating (Kirk and Holmes 1975; Lentz 1980; Roussy *et al.* 1985; Ofoli and Komolprasert 1988; Komolprasert and Ofoli 1989), we have not been able to find any related to the interactions of food and metal shielding during microwave heating. There are, however, several patents that describe the use of metal foils to modify microwave field intensity. Brown (1965) used aluminum foil to selectively shield the sensitive area in a compartment tray, claiming that the unshielded area controlled the heating rate of food. Winter (1981) made some holes on the aluminum top cover of a package to allow microwaves to penetrate upwardly from the bottom of the package. The holes also facilitated the release of moisture and pressure from the package during microwaving. Keefer (1987) used a specially designed lid to control browning and crisping of foods. The lid allowed microwaves to penetrate into a package but prevented them from escaping the package. The contents of these patents, unfortunately, are mostly descriptive, and provide little scientific details.

The interactions between food and metal shielding during microwaving are very complicated. They depend on the food, the design of metal shielding, and microwave intensity. Mathematical modeling of these interactions is a formidable task, and the validity of predicted results depends on many assumptions. As an initial step, we used an empirical approach with statistical design to gain a better understanding of the these complicated interactions. Specifically, the objective of this work was to study the effectiveness of using metal bands to improve the heating uniformity of a model food. Metal bands were chosen because they can be incorporated into the package easily and inexpensively.

MATERIALS AND METHODS

Materials

Cylindrical Pyrex glass beakers (600 ml) containing agar gel were used for the experiments. The beakers were chosen because their cylindrical shape resembled many commercially available microwaveable food packages. The beakers had an inner diameter of 84 mm and height of 120 mm.

The experimental units were cylindrical samples prepared by dissolving 12 g of agar powder (Difco Laboratories, Detroit, MI) into 388 g distilled water in a beaker to make up to 3% (w/w). The solution was heated, stirred, and cooled for at least 6 h at room temperature to allow for gel formation. The cylindrical sample gel was approximately 84 mm in diameter and 74 mm in height.

Design of Metal Shielding Patterns

Various shielding patterns were obtained by strategically placing 0.002 cm thick aluminum bands of various widths on the outer surface of the beaker (see examples in Fig. 1). For simple patterns (such as those consisting of all vertical bands or all horizontal bands), the design variables were the number, width (L_w), spacing (L_s), orientation of the bands (Θ), and % exposure area (A_e). The % exposure area was defined as

$$A_e = \frac{\text{exposed surface area}}{\text{total surface area}} \times 100 \tag{1}$$

where the top and the bottom of the beaker were not shielded, but they were included in the calculations of the surface areas. Among these five variables, however, only three were independent.

More complicated designs were also made by using both vertical and horizontal bands or by using a combination of bands with different widths. In the experiments, L_w varied between 1 to 6 cm, L_s varied between 0.5 to 4.5 cm, and Θ varied between 0 to 180°.

Parameter Definitions

Since the temperature profile inside a cylindrical sample was a function of both time and position, it was rather difficult and clumsy to compare it with the temperature profiles of other samples. To simplify the problem, the following two parameters were defined.

The first parameter, relative uniformity (RU), was defined as

$$RU = \frac{SD}{SD(open)} \times 100\% \tag{2}$$

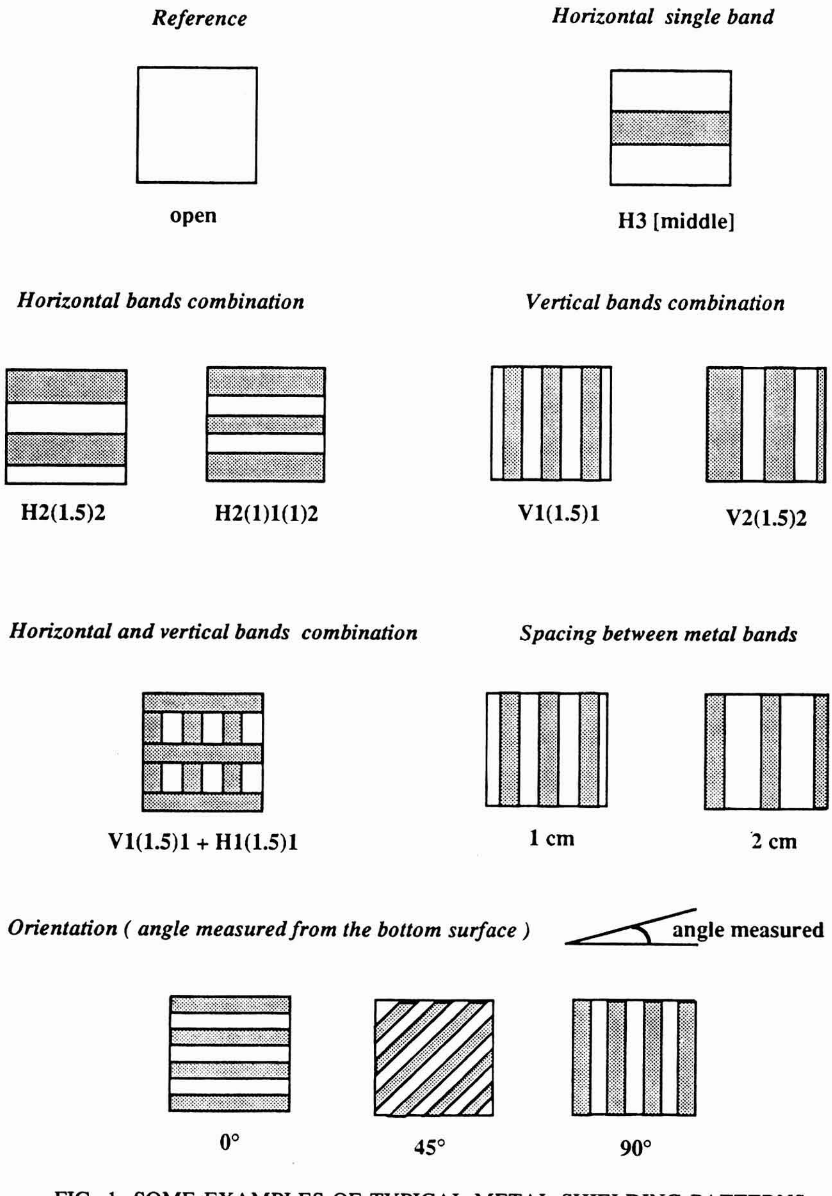


FIG. 1. SOME EXAMPLES OF TYPICAL METAL SHIELDING PATTERNS
The shaded areas represent the portions shielded by metal bands.

where SD and SD(open) are the standard deviations of heating rates measured at several locations of the shielded and unshielded cylindrical samples, respectively. The standard deviation (SD) is

$$SD = \sqrt{\frac{\Sigma(x_i - x_m)^2}{n - 1}} \tag{3}$$

where n is number of temperature probe locations, x_i is the heating rate at location i, and x_m is the average value of the heating rates at n different locations. Since SD is a measure of the spread of a distribution (the smaller the standard deviation, the more uniform is the distribution), RU provides a measure of the heating uniformity of the cylindrical sample. As RU decreases, the heating uniformity increases.

The second parameter, relative power absorption (RP), was defined as

$$RP = \frac{P}{P(\text{open})} \times 100\% \tag{4}$$

where P and P(open) are the power absorption of the shielded and unshielded (open) cylindrical sample, respectively. As RP increases, the power absorption of food model increases, or the power loss by the metal shielding pattern decreases. Both RU and RP have a range between 0 to 100%

Procedures

Heating Rate Distribution Measurement. Figure 2 is a schematic diagram of the experimental setup. The microwave oven was a Toshiba Model ERS-6830B, which had a rating at 2450 MHz, 720W maximum output, with a metallic stirrer and a magnetron located at the bottom. The power supply for the microwave oven was regulated with a voltage stabilizer (Trip Lite, Model 1200a, Chicago) to minimize possible fluctuations due to changes in the line voltage (Schiffmann 1986; Gerling 1978; Gerling 1987). During the experiment, the sample was raised 2 cm above the microwave oven floor using a styrofoam block. Depending on the experiment, 5–7 equally spaced fiberoptic temperature probes (Luxtron model type of ASC, MSA and MIW, Mountain View, CA) were placed along the z-axis and/or r-axis of each sample (Fig. 3, 4, and 5). The probes were connected to two Luxtron fiberoptic temperature acquisition systems (Model 755, Mountain View, CA). The samples were microwaved for 2–4 min at maximum power, and the temperature-time profiles at the probe locations were recorded. Each reported datum was the average of three replicates, with typical standard deviation was less than 10% of the average.

Average Power Absorption Measurement. The power absorbed by the sample during microwaving was assumed to be that by an equivalent weight of distilled water, based on the fact that the dielectric properties of the agar gel and distilled water were quite similar (Roebuck *et al.* 1975). For each pattern, 400 g of water

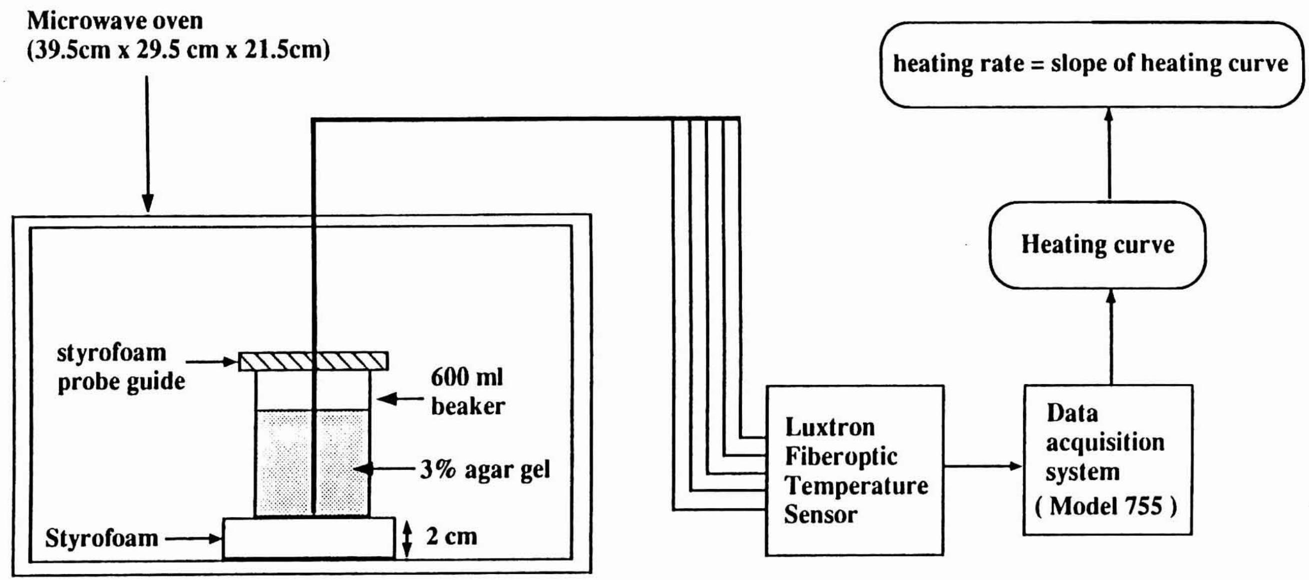


FIG. 2. A SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SETUP FOR MEASURING HEATING RATE DISTRIBUTION

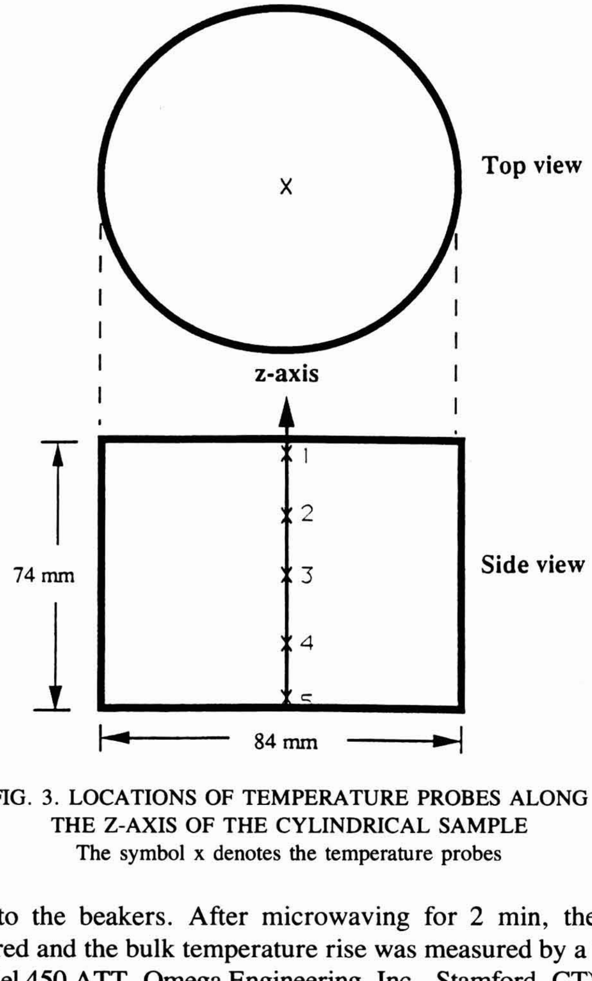


FIG. 3. LOCATIONS OF TEMPERATURE PROBES ALONG THE Z-AXIS OF THE CYLINDRICAL SAMPLE
The symbol x denotes the temperature probes

was poured into the beakers. After microwaving for 2 min, the water was thoroughly stirred and the bulk temperature rise was measured by a T-type thermocouple (Model 450 ATT, Omega Engineering, Inc., Stamford, CT). The power absorption (P) was calculated using the equation:

$$P = \frac{m\ C_p\ \Delta T}{\Delta t} \tag{5}$$

where C_p is the specific heat, m the mass, ΔT the temperature rise, and Δt the microwaving time.

Equation (5) assumed that the power absorbed was solely due to the microwave energy, there was no heat gain or loss to the surroundings, and C_p of water did not change with temperature. Each reported datum was the average of three replicates, with typical standard deviation was less than 5% of the average.

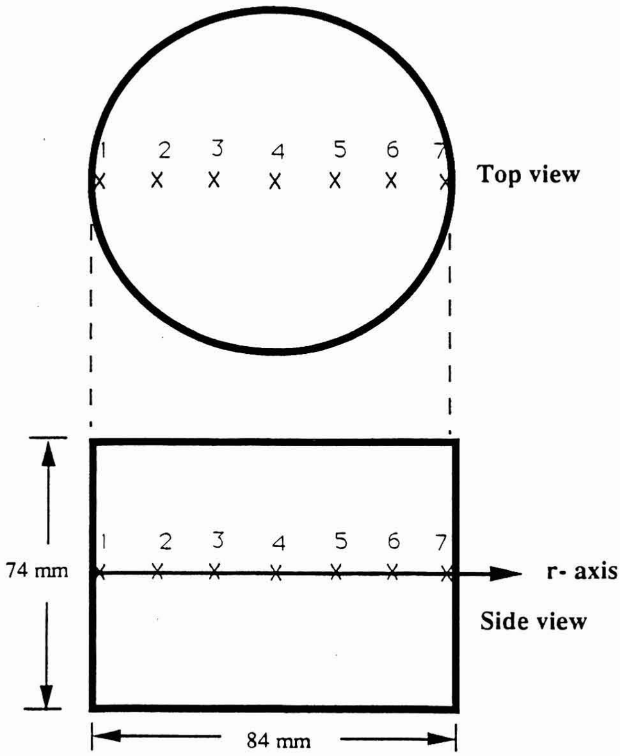


FIG. 4. LOCATIONS OF TEMPERATURE PROBES ALONG THE R-AXIS OF THE CYLINDRICAL SAMPLE
The symbol x denotes the temperature probes.

Experimental Design and Statistic Analysis. Response surface methodology (RSM) was used to analyze the strengths of Θ and L_s on RU and RP. A central composite rotatable design was used to minimize the number of experimental units involved, with ranges and intervals of experimental parameters similar to those of Cochran and Cox (1957) and Mullen and Ennis (1979). The theoretical and fundamental aspects of RSM can be found elsewhere (Cochran and Cox 1957; Myers 1971; Thompson 1982; Montgomery 1984).

RESULTS AND DISCUSSION

Heating Rate Pattern of Open Cylindrical Sample

Figure 6 shows the temperatures inside the open cylindrical sample at five locations as a function of time. As expected, the temperature increased as time pro-

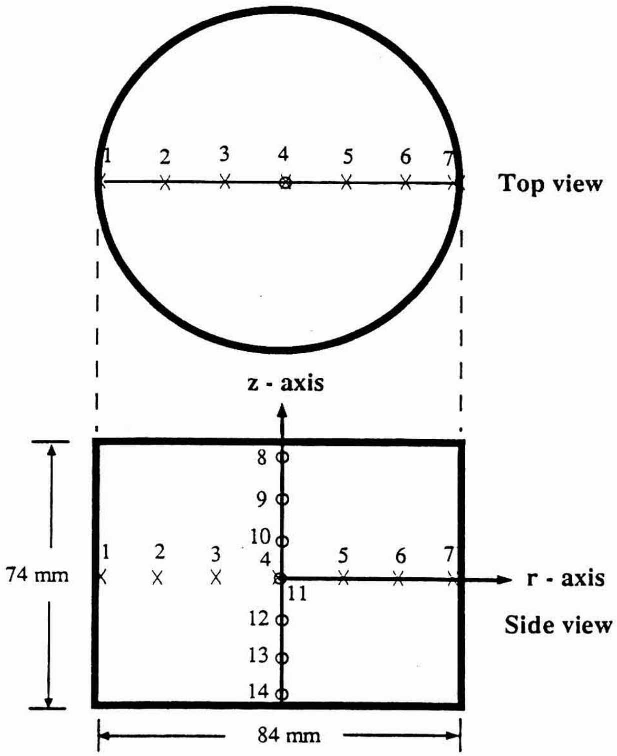


FIG. 5. LOCATIONS OF TEMPERATURE PROBES ALONG THE Z- AND R-AXIS OF THE CYLINDRICAL SAMPLE
The symbol x denotes the temperature probes.

gressed regardless of the location, but the extent of increase depended on the heating rate (dT/dt). A typical temperature-time curve (Fig. 7) for each location shows that the heating rate or the slope f the curve was almost constant until the temperature reached the boiling point of water (100C). It is noteworthy that during the period when the heating rate was constant, RU did not change with time. Experiments were also conducted to show that RP did not change significantly with time.

For simplicity, the constant heating rate instead of temperature as a function of time was used for the following analysis. Figure 8 shows the heating rates at 21 locations in the unshielded (open) cylindrical sample. To study the variation along the r-axis at three different z-locations, the relevant data were plotted in Fig. 9 (compare the location numbers in Fig. 8 and 9), showing that the heating rate at the geometric center was at least twice as high as most other locations. Similarly, to study the variations along the z-axis at three different r-locations, we plotted the data in Fig. 10 (compare the location numbers in Fig. 8 and 10),

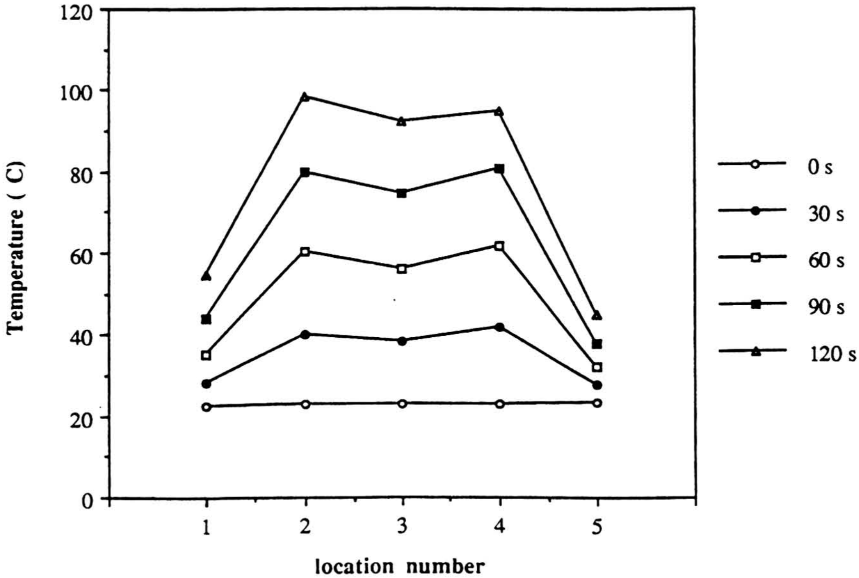


FIG. 6. TEMPERATURE DISTRIBUTION OF UNSHIELDED (OPEN) CYLINDRICAL SAMPLE DURING MICROWAVE HEATING (REFER TO THE LOCATION NUMBERS IN FIG. 3)

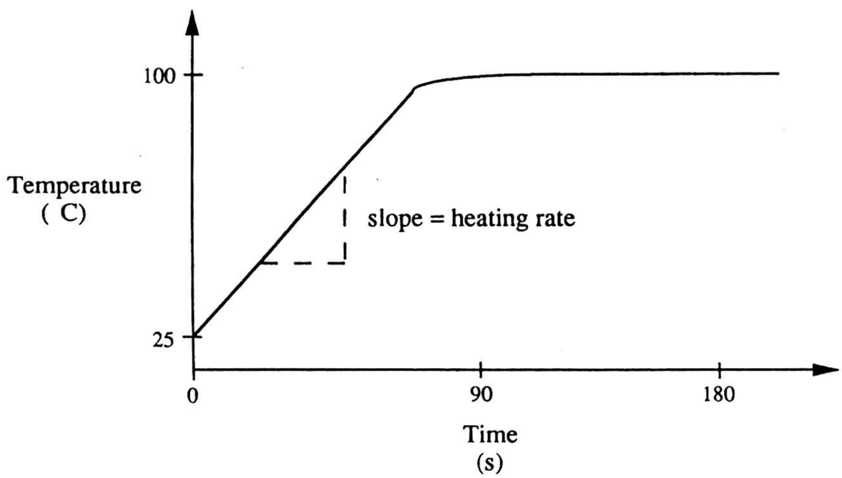


FIG. 7. TYPICAL TEMPERATURE-TIME CURVE DURING MICROWAVE HEATING

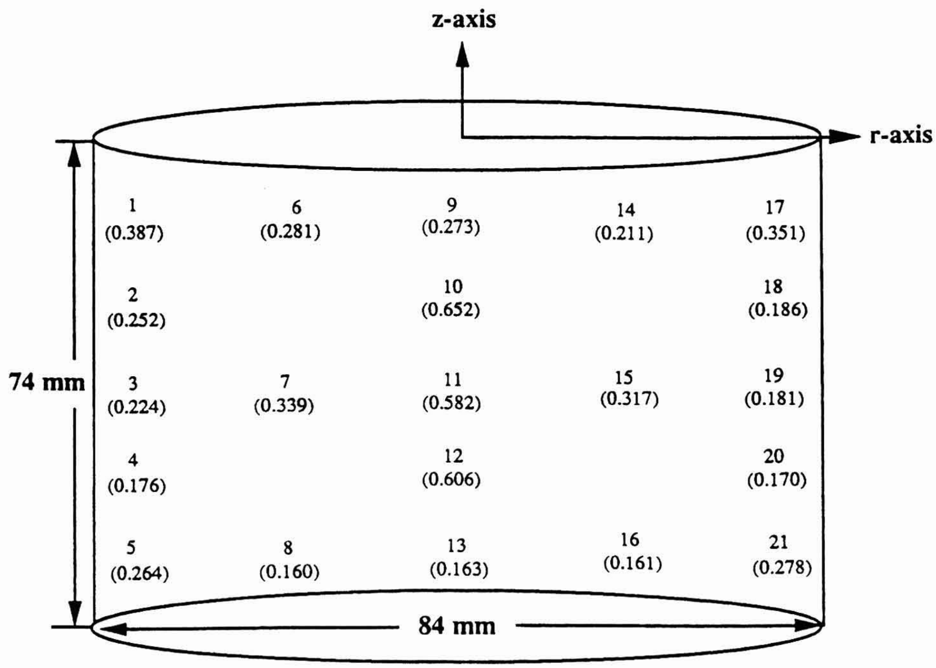


FIG. 8. HEATING RATES AT DIFFERENT LOCATIONS INSIDE THE OPEN CYLINDRICAL SAMPLE DURING MICROWAVE HEATING

The integers are the location numbers, and the values inside the brackets are the heating rates.

showing that the heating rates near the geometric center (location number 10, 11, 12) were also at least twice as high as most other locations.

Figures 9 and 10 show clear evidence of center heating, a phenomenon attributed to the focusing of microwave that often occurs in cylinders and spheres. Center heating is a function of microwave frequency (Copson 1975), size and conductivity of the food (Keenan 1983). Ohlsson and Risman (1978) reported that center heating was more pronounced in spherical than in cylindrical foods. Figures 9 and 10 also show that the heating rate distributions along the r-axis and z-axis were quite symmetric, indicating that the microwave oven generated a reasonably uniform electromagnetic field.

The heating rate at the geometric center (location number 11) was the highest in Fig. 9, but it was lower than location numbers 10 and 12 in Fig. 10. The penetration depth (Von Hippel 1954) of the 3% Difco agar may be approximated to be 26.8 mm, using the published dielectric constant κ' and dielectric loss κ'' of 2.7% Difco agar gel measured at 3 MHz (Roebuck and Goldblith 1975). Since the diameter and height of the sample (84 and 74 mm, respectively) are more than

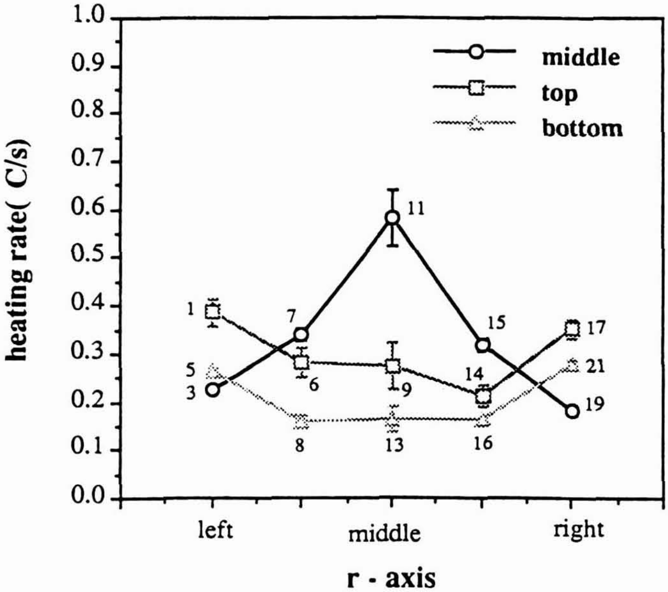


FIG. 9. HEATING RATES ALONG THE R-AXIS AT THREE Z-AXIS LOCATIONS (TOP, MIDDLE, AND BOTTOM)
The data were taken from Fig. 8, and the integers are the location numbers.

twice this penetration depth, if the microwave penetrates in only one dimension, the heating rate pattern is likely to have the shape as in Fig. 10. In reality, the microwaves penetrate the agar in three dimensions. Consequently, the heating rate pattern is difficult to predict: i.e., it can also have the shape as shown in Fig. 9.

Figures 8 through 10 clearly show that there were significant heating rate variations inside the open sample. Since the variations were the largest in the z-axis through the geometric center (location number 9, 10, 11, 12, 13), only the heating rates of these locations were measured for the screening experiments below.

Screening Test to Identify Design Patterns

Obviously, myriad patterns could be constructed. It was necessary to conduct screening experiments to identify those patterns that were of most interest. In Table 1, four groups of design patterns were examined. The standard deviations were calculated along the z-axis (based on five locations) and along the r-axis (based on seven locations), individually. The RU_z values, RU_r values, and RP values were also calculated, using the open sample as a reference. These calculated data indicated that the open sample had the largest heating rate variation because

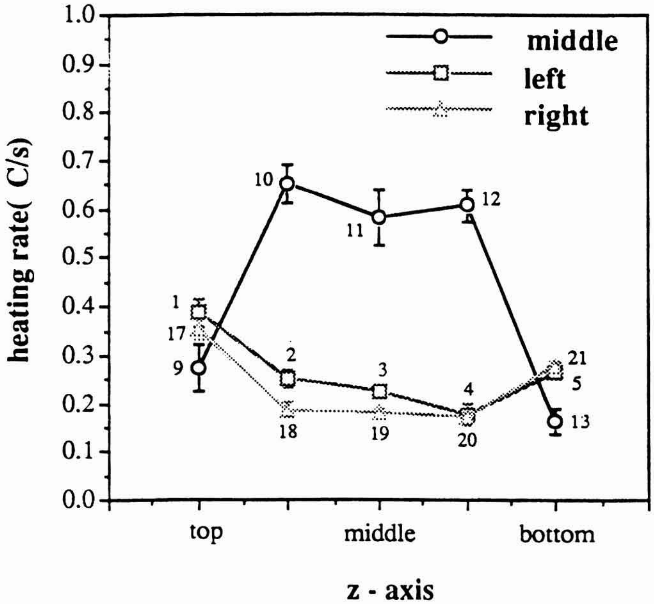


FIG. 10. HEATING RATES ALONG THE Z-AXIS AT THREE R-AXIS LOCATION (LEFT, MIDDLE, AND RIGHT)
The data were taken from Fig. 8, and the integers are the location numbers.

all the shielded samples had lower RU values. The lower the RU, the more uniform is the heating rate distribution. As expected, the open sample also had the highest RP value.

Group I involved placing a horizontal single band either on the top, middle, or bottom portion of the sample. L_w ranged from 2 to 5 cm, and the corresponding heating rate profiles were shown in Fig. 11. In general, shielding the top portion reduced the heating rate at the top but shifted the hottest point to the bottom. Similarly, shielding the bottom portion reduced the heating rate at the bottom but shifted the hottest point to the top. The effect of shielding the middle portion depended on L_w: for 2 and 3 cm bands, the heating rate was reduced not at the geometric center (in fact, it appears to be higher than that of the open sample) but at the adjacent locations; for 4 and 5 cm bands, there was a relatively uniform reduction of the heating rates. It is noteworthy that although the 6 cm band yielded an excellent RU_z (38.3%), the RU_r (68.7%) was relatively high. The other patterns were not acceptable because the RUs were too high.

Group II involved placing several horizontal bands instead of a single band. Various L_w and L_s of the bands were used. The patterns did not show improvement compared to group I because the RUs were high.

TABLE 1.
SCREENING TEST RESULTS OF DIFFERENT METAL SHIELDING PATTERNS

pattern [a] items	A_e [b] (%)	SD_z [c]	RU_z (%)	SD_r [d]	RU_r (%)	P [e] (W)	RP (%)
Reference							
open*	100.0	0.232	100.0	0.179	100.0	509.3	100.0
Group I. Horizontal single band							
H2 [top]	82.8	0.212	91.4	-----	-----	502.3	98.6
H2 [middle]	82.8	0.217	93.5	-----	-----	500.5	98.3
H2 [bottom]	82.8	0.214	92.2	-----	-----	490.7	96.3
H3 [top]	74.3	0.224	96.6	-----	-----	487.4	95.7
H3 [middle]	74.3	0.167	71.9	-----	-----	484.6	95.2
H3 [bottom]	74.3	0.206	88.8	-----	-----	481.9	94.6
H4 [top]	65.7	0.192	82.8	-----	-----	467.0	91.7
H4 [middle]	65.7	0.124	53.5	0.149	83.2	466.0	91.5
H4 [bottom]	65.7	0.197	84.9	-----	-----	461.8	90.7
H5 [top]	57.1	0.171	73.7	-----	-----	441.3	86.6
H5 [middle]	57.1	0.114	49.1	0.146	81.5	444.1	87.2
H5 [bottom]	57.1	0.169	72.8	-----	-----	438.6	86.1
H6 [middle]	48.5	0.089	38.3	0.123	68.7	426.0	83.6
Group II. Horizontal bands combination							
H2(1.5)2	65.7	0.213	91.8	-----	-----	492.1	96.6
H2(1)1(1)2	57.1	0.175	75.4	0.119	66.5	463.2	90.9
H2(1)2(1)1	57.1	0.221	95.2	-----	-----	490.7	96.3
H1(1)1(1)1	74.3	0.195	84.1	-----	-----	483.7	95.0
H1(1.5)1(1.5)1	74.3	0.203	87.5	-----	-----	480.9	94.4
Group III. Vertical bands combination							
V1(1.5)1	73.8	0.108	46.6	0.102	56.9	467.2	91.7
V2(1.5)2	61.9	0.106	45.6	0.097	54.2	467.0	91.7
V3(1.5)3	57.2	0.107	46.1	0.072	40.2	455.8	89.5
V1(2)1	78.2	0.124	53.4	0.096	53.6	468.3	91.9
V1(2.5)1	80.6	0.141	61.0	0.096	53.6	484.6	95.2
Group IV. Horizontal and vertical bands combination							
V1(1.5)1+H1(1.5)1	58.5	0.045	19.4	-----	-----	415.3	81.5
V2(1.5)2+H1(1.5)1	51.6	0.043	18.5	-----	-----	411.6	80.8
V1(3)1+H1(2)1	64.3	0.114	49.1	0.097	54.2	434.8	85.4

[a] notations of metal shielding patterns (also see Figure 1)
integer : L_w (cm)
[ ] : specify offset position of the bands
( ) : specify L_s (cm)
H : horizontal pattern
V : vertical pattern

[b] $A_e\,(\%) = \frac{\text{exposure area}}{\text{total surface area}} * 100\%$

[c] SD_z = standard deviation of heating rates at z-axis (see location number 9, 10, 11, 12, 13 in Figure 8)

[d] SD_r = standard deviation of heating rates in seven locations at r-axis with equal spacing (see Figure 4)

[e] P = average power absorption of distilled water determined by calorimetric method

* open = open cylindrical sample without metal shielding

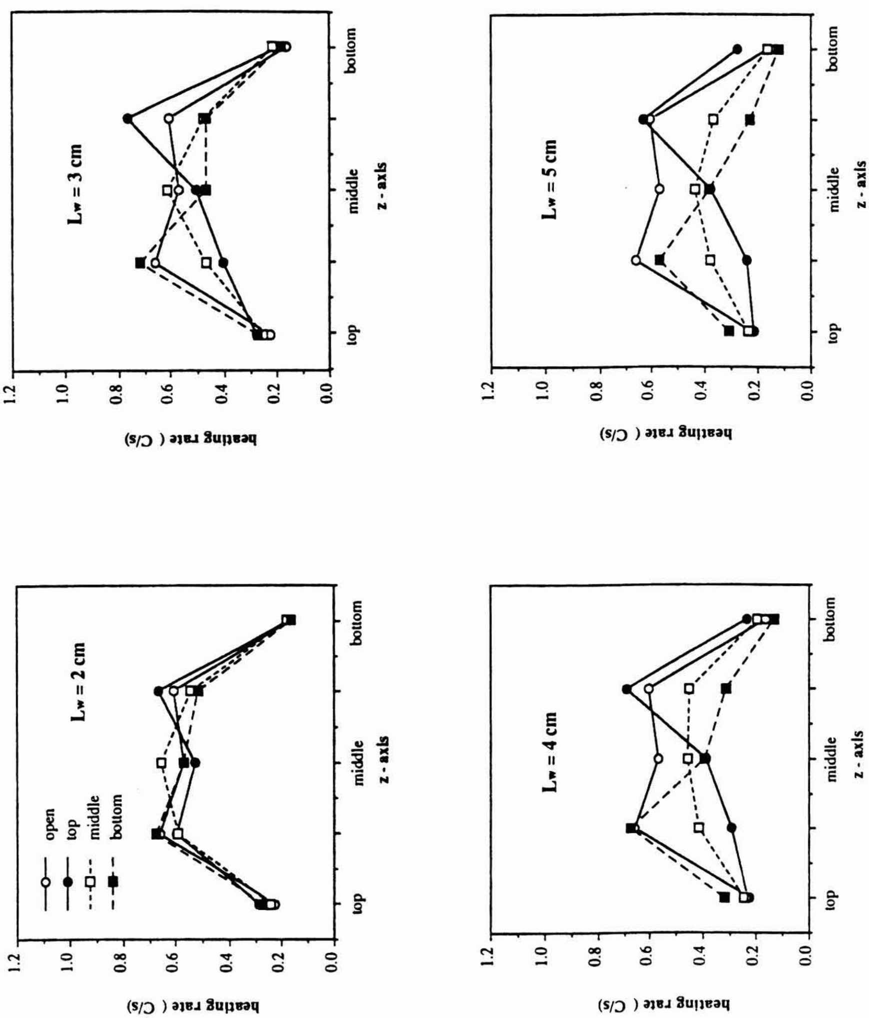


FIG. 11. HEATING RATE DISTRIBUTIONS ALONG THE Z-AXIS FOR SHIELDING PATTERNS WITH L_W OF 2, 3, 4, 5 CM

Group III involved placing several vertical bands on the sample. The design variables were L_w and L_s. In general, the patterns could greatly improve heating uniformity with little sacrifice in power loss. For example, the V1(1.5)1 pattern achieved a good RU_z (46.6%), while retaining a relatively high RP (91.7%).

Group IV involved horizontal and vertical band combinations. The first two patterns clearly demonstrated that shielding patterns had profound effects on the heating uniformity: the RU_z values of these patterns were much lower than other patterns of comparable A_e. However, the RP values of these two patterns were also the lowest.

The effects of A_e on RU_z and RP were also examined. In Fig. 12, the data in columns 4 and 8 of Table 1 were plotted against the data in column 2. The figure shows that RP correlated quite well with A_e, albeit the data representing many different design patterns. In general, RP decreased only slightly with decreasing A_e. For example, when A_e is 57% (43% of the surface area is shielded), RP is 90% (only 10% loss): in this case, if 3 min are required to heat the open sample to a certain bulk temperature, it takes only 3.3 min (an addition of 0.3 minute) to heat the shielded sample to the same temperature. On the other hand, RU did not correlate well with A_e, and it depended strongly on the design pattern used. For example, at A_e of 57%, greatly different values of RU are obtained. The above discussion suggests that it is possible to design shielding patterns that can greatly reduce RU without greatly increasing the heating time.

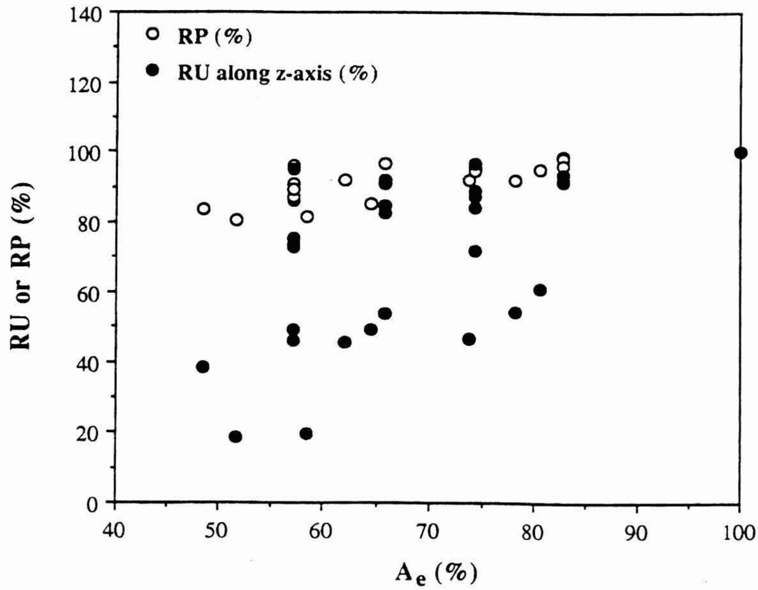


FIG. 12. PLOT OF RU_Z AND RP VS A_e

Since temperature is a function of both z-axis and r-axis, two reasonable requirements for good heating uniformity are: (1) SD_z and SD_r (or their corresponding RUs) must be small, and (2) SD_z, SD_r, and overall standard deviation, SD_o, must be nearly the same. The open sample has rather poor heating uniformity because its SD_z, SD_r, and SD_o values are relatively large and vary greatly among one another (0.232, 0.179, and 0.196, respectively). In contrast, the pattern V1(1.5)1, for example, has good heating uniformity because its SD_z, SD_r, and SD_o values are relatively small and close to one another (0.108, 0.102, and 0.105, respectively).

Effect of Θ and L_s

A good shielding pattern should be one that yields good heating uniformity (low RU) and power absorption (high RP). In Table 1, there are several candidates of good shielding patterns, depending on whether lowering RU or maintaining RP is more desirable.

The effects of two key design variables, Θ and L_s, were studied. The V1(1.5)1 was chosen as the base pattern because it yielded reasonably low RUs and high RP, and its construction required relatively little metal shielding. The strategy here was: (1) to examine the effects of Θ and L_s individually over a wide range of conditions to locate the region of most interest, and (2) to examine the region of interest more closely using suitable statistical analysis.

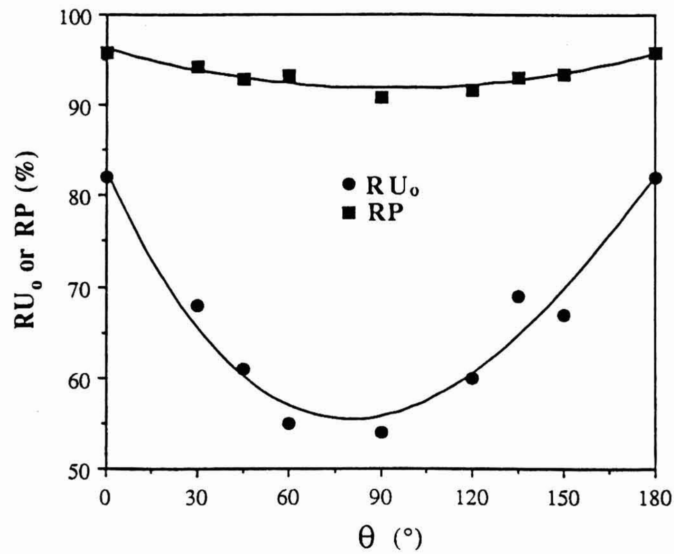


FIG. 13. PLOT OF RU_O AND RP VS Θ

Figure 13 shows the plots of RU_o and RP versus Θ. RU_o was the overall relative uniformity obtained from 14 temperature measurements (7 along the z-axis and 7 along the r-axis in Fig. 5). RU_o and RP varied parabolically with Θ, both displaying a minimum at 90° (i.e., when the bands are vertical). RU_o is strongly affected by Θ: for example, RU_o at 0° (82%) is much larger than the RU_o at 90° (54%). In contrast, RP is very little affected by Θ. It should be mentioned that Θ changes the A_e only slightly (less than 2%).

Figure 14 shows the plots of RU_o and RP versus L_s. The function of RU_o versus L_s first decreases, passes through a minimum (between 1.5 to 2.0 cm), and then increases. The high RU_o at the initial portion of the function is due to excessive shielding, the high RU_o at the latter portion is due to inadequate shielding, and somewhere in between there is a portion where RU_o reaches a minimum or optimum. Again we observe that RP is little affected: increasing L_s increases RP only slightly, regardless of the fact that A_e is significantly decreased (A_e at L_s of 0.5 and 4.5 cm are 57 and 88%, respectively).

Thus, Fig. 13 and 14 have clearly shown that RU_o are significantly affected by Θ and L_s. Since it was possible to vary both Θ and L_s at the same time, we used statistical analysis to examine if there was a strong interaction between these two variables.

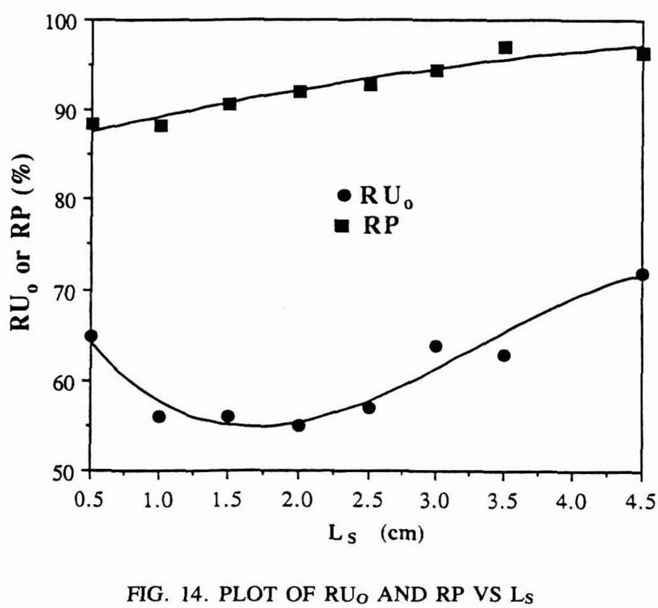


FIG. 14. PLOT OF RU_o AND RP VS L_s

Statistical Analysis

The response surface methodology (RSM) with a central composite rotatable design (Cochran and Cox 1957) was used to examine the effect of changing Θ and L_s simultaneously. The selection of levels of Θ and L_s was based on preliminary experiments: the regions of interest for Θ was 48 to 132° and for L_s was 1.3 to 2.7 cm. Each point in the central composite rotatable design was repeated three times.

The statistics software JMP (SAS 1991) was used to fit the experimental data with the following second order polynomial models for RU_o and RP:

$$RU_o = a_o + a_1X_1 + a_2X_2 + a_{11}X_1^2 + a_{22}X_2^2 + a_{12}X_1X_2 \tag{6}$$

$$RP = b_o + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2 \tag{7}$$

where the values a_i and b_i are regression parameters; the response variables are RU_o and RP; the coded independent variables are X_1 for Θ and X_2 for L_s.

From analysis of variances of the experimental data, both the RU_o and RP models were highly significant ($p < 0.01$), there was no lack of fit, and the models were adequate. Table 2 shows the estimated values and the statistical significance (based on t-test) of the parameters. The interaction terms, a_{12} and b_{12}, are not statistically significant at the 0.01 level.

From the result of Table 2, Eq. (6) and (7) may be simplified as

$$RU_o = 56.6197 + 7.7670X_1^2 \qquad (R^2 = 0.87) \tag{8}$$

$$RP = 92.6999 + 1.2158X_2 + 1.3316X_1^2 \qquad (R^2 = 0.88) \tag{9}$$

Figure 15 shows the 3-dimensional response surfaces of RU_o and RP as function of both Θ and L_s created by using the software Mathematica (Wolfram 1991). In the figure, RU_o is affected only by Θ, but RP is affected both by Θ and L_s. Since Θ affects both RU_o and RP, it is a more important factor compared to L_s.

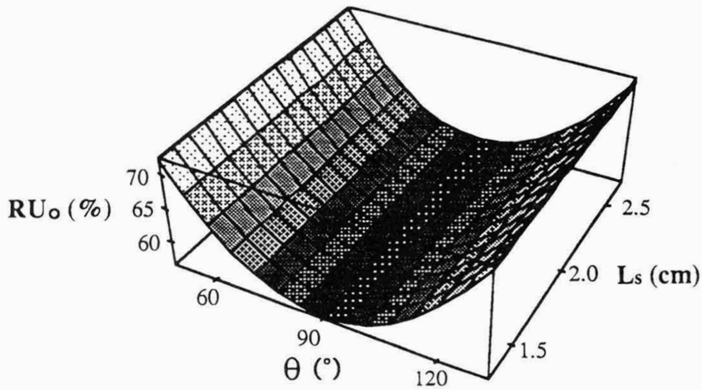
CONCLUSION

Shielding using metal bands was an effective way to improve the microwave heating uniformity of the cylindrical samples. The orientation of the band, Θ, is an important design variable. It is possible to design shielding patterns for reducing the relative uniformity (RU), without significantly reducing the relative power

TABLE 2.
ESTIMATED REGRESSION PARAMETERS OF THE SECOND ORDER POLYNOMINIALS IN EQUATIONS (6) and (7)

RU_o		RP	
a_0	56.6197 *	b_0	92.6999 *
a_1	- 0.5165	b_1	- 0.1134
a_2	0.9864	b_2	1.2158 *
a_{11}	7.7670 *	b_{11}	1.3316 *
a_{22}	0.3648	b_{22}	0.0562
a_{12}	- 0.95	b_{12}	0.05

* it is statistically significant in t - test at 0.01 level



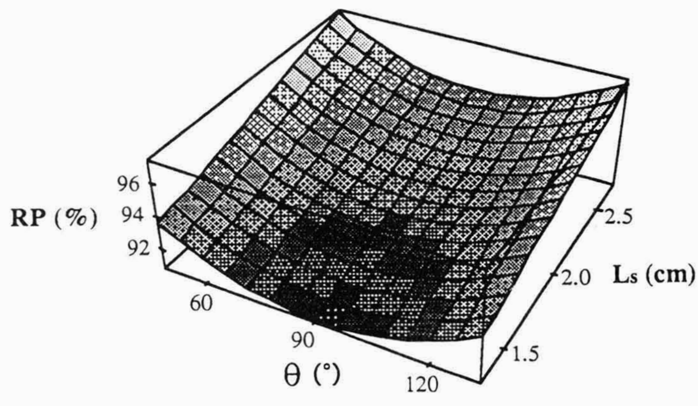


FIG. 15. RESPONSE SURFACES OF THE RU_o AND THE RP MODELS AS FUNCTION OF θ AND L_s

absorption (RP). We should mention, however, that the results were obtained under rather restricted conditions. More experimental and theoretical works are needed to elucidate the effect of metal shielding on microwave heating of foods under other conditions, such as when using foods of various dielectric properties, sizes, and geometries.

NOMENCLATURE

A_e	% exposure area (%)
L_s	Spacing between metal bands (cm)
L_w	Width of metal band (cm)
P	Power absorption (W)
RP	Relative power absorption (%)
RU	Relative uniformity (%)
RU_z	Relative uniformity along z-axis (%)
RU_r	Relative uniformity along r-axis (%)
RU_o	Relative uniformity along both z-axis and r-axis (%)
SD_z	Standard deviation of heating rate at different locations along z-axis
SD_r	Standard deviation of heating rate at different locations along r-axis
SD_o	Standard deviation of heating rate at different locations along both z-axis and r-axis
X_1	Coded variable of Θ (dimensionless)
X_2	Coded variable of L_s (dimensionless)
Θ	Orientation (angle) of metal band (°)

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SHELF-LIFE EXTENSION AND IMPROVEMENT OF THE MICROBIOLOGICAL QUALITY OF SMOKED SALMON BY IRRADIATION

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ABSTRACT

Cold-smoked salmon locally available was irradiated at 2 and 4 kGy. Irradiated and unirradiated samples were stored at refrigeration temperature (2–3C). Microbiological and sensory qualities were studied immediately after irradiation and during storage. Irradiation at 2 kGy caused a great reduction in all the tested microbial population, thus improving the hygienic quality of smoked salmon to meet the microbiological limits for the top-grade quality. Moreover, irradiated samples at 4 kGy were free from coliform bacteria, fecal streptococci and Staph. aureus *over the entire storage period. Unirradiated samples reached the maximum accepted mesophilic plate count after only one month of storage, while those irradiated at 2 and 4 kGy reached this level after 3 and 4 months, respectively. No differences in sensory qualities were found by the taste panel between unirradiated samples and those irradiated at 2 Kgy, but they observed a distinct loss in normal cherry red color of the samples irradiated at 4 kGy.*

INTRODUCTION

The production and consumption of smoked fish products have received considerable attention in Egypt in the last decade. Many types of smoked fish products are now produced in Egypt: cold-smoked herrings, cold-smoked salmon, hot-smoked mackerel and semi-hot smoked herring. In spite of that, studies on the microbiological quality of smoked fish in Egypt is limited. The most common method of fish smoking is the cold smoking process, which involves treating presalted fish by certain wood smoke at an air temperature not higher than 28–30C (Zaitsev *et al.* 1969; Bannerman 1980). Therefore, the temperature used in cold smoking has little effect upon the general flora present. Consequently, cold-smoked fish products that are lightly salted and not given a long drying process have high numbers of both spoilage and pathogenic microorganisms and have poor keeping quality.

Although cold-smoked salmon represents a very small market in Egypt compared to cold-smoked herrings, it is considered the most expensive item of all foods. Cold smoked salmon is a perishable and valuable fish product. To maintain its good quality and to prevent food-borne illness it must be preserved after smoking by a satisfactory method of preservation. Freezing is technically satisfactory, but it is expensive in addition to impairing the texture and flavor of smoked fish products. Chilling provides only limited shelf-life extension and does not improve the hygienic quality of the product.

A promising new method of food preservation is the use of ionizing radiation. It has been reported by numerous investigators (Emerson *et al.* 1966; Kumta and Sreenivasan 1967; Gonzalez 1981; Venugopal *et al.* 1987; Hammad *et al.* 1988; Radi *et al.* 1991) that radurization has been successfully used for extending the shelf-life of fish and fishery products. Most of the vegetative bacteria, including pathogens, are eliminated by low doses of gamma radiation, thereby rendering a product with a longer shelf-life and improved hygienic quality, but this method has not been tried with smoked salmon.

The purpose of this study was to assess the microbiological quality of cold-smoked salmon and to investigate the possibility of extending its shelf-life by gamma irradiation. Improvement of the hygienic quality of these cold-smoked fish products by gamma irradiation was also considered, since cold-smoked salmon is always eaten as is with no further heating.

MATERIAL AND METHODS

Samples

Cold-smoked salmon samples used in this experiment were obtained from the Fish Smoking Plant at 10th of Ramadan, Cairo. The traditional method of cold smoking with light salting was used in the processing of this cold smoked salmon.

Irradiation Processing

Cold-smoked salmon samples, packed in oxygen impermeable plastic films bags, each containing 250 g of thin sliced salmon, were irradiated by the Gamma Chamber 4000 A (Indian Atomic Energy LTD) located at the National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt. A dose rate of 80 Gy/min was used. Smoked samples were exposed at room temperature to 2 and 4 kGy. The unirradiated and irradiated samples were then stored at refrigeration temperature (2–3C) until they were rejected. Rejection of the samples was based on reaching the standard mesophilic plate count $> 10^6$ cfu/g and developing sour flavor.

Microbiological Methods

Total mesophilic aerobic bacterial count and psychrophilic bacterial counts were determined according to the method of the International Commission on Microbiological Specifications for Foods (ICMSF1978) using plate count agar (Oxoid) medium. Lactobacilli were enumerated on MRS Agar medium (Oxoid Limited 1982). Yeasts and molds were counted on Czapeks Dox agar medium, while fecal streptococci were enumerated on Kanamycin aesculin azide agar medium (Oxoid Limited 1982). *Staphylococcus aureus* was enumerated by the method of Baird-Parker (1962) using Baird-Parker agar medium. *Clostridium perfringens* was detected according to Stephen *et al.* (1975) using fluid thioglycolate and sulfite-polymixin b-sulfadiazine (SPS) agar medium.

Chemical Methods

Smoked salmon samples were analyzed for their moisture and salt content according to AOAC (1975).

Sensory Evaluation

Evaluation of color, flavor and texture of unirradiated and irradiated smoked salmon samples was carried out immediately after irradiation and at monthly intervals on the same day as the microbiological analyses. A panel of six members from National Center for Radiation Research and Technology was employed. A 9-point hedonic scale was used (Ampola *et al.* 1969) in which: 9 = excellent; 8 = very good; 7 = good; 6 = tolerable; 5 = moderate; 4 = acceptable; 3 = rejectable; 2 = bad and 1 = very bad. A descriptive scale for sensory evaluation of cold-smoked salmon is shown in Table 1 (Madhavan and Kumta 1973; Ostrander and Martinsen 1976).

TABLE 1.
DESCRIPTIVE SCALE FOR SENSORY EVALUATION OF COLD-SMOKED SALMON

Scores	Characteristics		
	Color	Flavor	Texture
9/8	Cherry red	Normal	No criticism
7/6	Light pinkish	Faint	No criticism
5/4	Beige-white	Undistinguishable, slight rancid	Slightly soft
3/2	Dull,off,white	Pronounced rancid, sour taste	Soft
1	White	Off-flavor	Mushy

RESULTS AND DISCUSSION

Chemical Analysis

Among the most important factors affecting the growth of microorganisms in smoked fish are salt and moisture content. Therefore, salt and moisture content of cold-smoked salmon was studied. Table 2 shows the results of moisture and salt content as affected by irradiation doses and storage. The moisture content of smoked salmon was 60.78% and salt content was 1.80%, indicating that this product had high moisture content and low salt content. Therefore cold-smoked

TABLE 2.
MOISTURE AND SALT CONTENT OF COLD-SMOKED SALMON AS AFFECTED BY IRRADIATION AND STORAGE

Storage period [Months]	Moisture content %			Salt content %		
	0 kGy	2 kGy	4 kGy	0 kGy	2 kGy	4 kGy
0	60.78	60.08	60.56	1.80	1.74	1.88
1	59.99	60.35	61.15	1.78	1.89	1.78
2	61.16	61.02	60.87	1.79	1.65	1.65
3	---	59.87	59.79	---	1.90	1.80
4	---	---	61.09	---	---	1.85

salmon products have a low keeping quality and need a satisfactory method of preservation to minimize loss of quality. Irradiation at the two levels used (i.e., 2 and 4 kGy) had no effect on both moisture and salt content, since these samples were packed in sealed impermeable plastic bags.

Microbiological Assessments

Tabulated results in Table 3 indicate that the counts of all tested microbial groups were in the accepted range for cold-smoked fish. However, these counts were higher than those reported for top grade cold-smoked fish or even for grade 2 quality. Refai (1979) reported that cold-smoked fish products should have mesophilic aerobic bacterial counts of less than 10^6 cfu/g and *Staph. aureus* of less than 10^3 cfu/g. On the other hand, Korkeala and Pakkala (1988) showed that the total bacterial counts for top grade quality cold-smoked fish are $\leqslant 5.0 \times 10^2$ cfu/g, and $\leqslant 5.0 \times 10^3$ cfu/g for grade 2 quality cold-smoked fish. The relatively high counts might be due to many factors, among which are light salting and, consequently, low salt concentration in the finished product, high moisture content, low smoking temperature, as well as contamination with different kinds of microorganisms due to the methods used in handling, slicing and packaging. Therefore, we tried to improve the hygienic and microbiological quality of cold-smoked salmon by gamma irradiation to meet the microbiological limits for the highest quality cold-smoked fish.

Results in Table 3 indicate that gamma irradiation caused a great reduction of all microorganisms tested. A gamma irradiation dose of 2 kGy reduced the counts of total mesophilic aerobic bacteria, psychrophilic bacteria, lactobacilli, yeasts and fecal streptococci by 98.8, 98.3, 96.8, 93.6 and 97.7%, respectively, while coliform and *Staph. aureus* cells were almost completely destroyed. Furthermore, a 4-kGy dose reduced mesophilic aerobic bacteria, psychrophilic bacteria, lactobacilli and yeasts by about 99.7, 99.6, 99.1 and 98.8%, respectively, while it almost completely destroyed fecal streptococci cells. Many investigators, through their studies on the effect of irradiation on microorganisms contaminating fish products, reached the same results (Emerson *et al.* 1966; Miyauchi and Teeny 1970; Hammad *et al.* 1988; Radi *et al.* 1991). It is evident from the reduction percentage of microorganisms caused by irradiation that yeasts were the most radiation resistant, followed by lactobacilli. The radiation resistance of yeasts in comparison with bacteria was reported by Ingram and Farkas (1977) and by the ICMSF (1980), while the radiation resistance of lactobacilli compared to other bacteria was reported by Hastings *et al.* (1986). It is also evident that fecal streptococci withstand a 2-kGy gamma irradiation dose, while coliforms and *Staph. aureus* do not. A 4-kGy gamma irradiation dose was sufficient for destruction of fecal streptococci cells in addition to coliforms and *Staph. aureus*.

TABLE 3.
MICROBIOLOGICAL COUNTS OF COLD SMOKED SALMON AS AFFECTED BY IRRADIATION AND STORAGE

Assessments	Storage period [Months]	0 kGy	2 kGy	4 kGy
Mesophilic aerobic bacterial count	0	$2.9x10^5$	$3.5x10^3$	$9.8x10^2$
	1	$6.2x10^6$	$9.0x10^3$	$2.4x10^3$
	2	$7.5x10^7$	$1.7x10^5$	$1.1x10^4$
	3	---	$8.8x10^6$	$1.8x10^5$
	4	---	---	$6.7x10^6$
Psychrophilic bacterial count	0	$5.0x10^5$	$8.3x10^3$	$2.1x10^3$
	1	$7.8x10^6$	$1.5x10^4$	$5.2x10^3$
	2	$8.5x10^7$	$2.0x10^5$	$1.5x10^4$
	3	---	$2.2x10^7$	$2.6x10^5$
	4	---	---	$8.0x10^6$
Lactobacilli	0	$1.0x10^5$	$3.2x10^3$	$9.2x10^2$
	1	$3.7x10^6$	$8.8x10^3$	$2.1x10^3$
	2	$1.3x10^8$	$8.0x10^4$	$9.0x10^3$
	3	---	$8.6x10^6$	$1.2x10^5$
	4	---	---	$5.8x10^6$
Yeasts	0	$6.2x10^3$	$4.0x10^2$	7.2x10
	1	$4.0x10^4$	$7.6x10^2$	9.0x10
	2	$4.7x10^5$	$9.1x10^3$	$2.2x10^2$
	3	---	$1.2x10^5$	$6.6x10^3$
	4	---	---	$1.7x10^5$
Coliform bacteria	0	$3.4x10^3$	<10	<10
	1	$9.4x10^2$	<10	<10
	2	$7.0x10^2$	<10	<10
	3	---	<10	<10
	4	---	---	<10
Fecal streptococci	0	$8.6x10^3$	$2.0x10^2$	$<10^2$
	1	$9.3x10^3$	$<10^2$	$<10^2$
	2	$5.0x10^4$	$<10^2$	$<10^2$
	3	---	$<10^2$	$<10^2$
	4	---	---	$<10^2$
Staphylococcus aureus	0	$2.0x10^2$	$<10^2$	$<10^2$
	1	$7.6x10^2$	$<10^2$	$<10^2$
	2	$1.9x10^3$	$<10^2$	$<10^2$
	3	---	$<10^2$	$<10^2$
	4	---	---	$<10^2$

During storage of smoked salmon samples at refrigeration temperature (2–3C) there was a progressive increase in the counts of mesophilic aerobic bacteria, psychrophilic bacteria, lactobacilli and yeasts, but the rate of increase was much higher in unirradiated samples in comparison with irradiated ones. That is normal and expected because the cold-smoked salmon samples had low salt content and high moisture content (Table 2), indicating that this product had a relatively high water activity that could enable microbiological proliferation. In other words, the salt content in concentrations normally used in cold-smoked salmon was not enough to prevent microbial multiplication. Control samples reached the rejection level (mesophilic aerobic bacterial count > 10^6 cfu/g) after only one month of storage at 2–3C, while those irradiated at 2 and 4 kGy reached this rejection level after 3 and 4 months, respectively. It is clear from the results in Table 3 that lactobacilli tend to dominate the microbial population in smoked salmon and that yeast counts markedly increase at the end of storage period, indicating that the loss of quality and spoilage of cold-smoked salmon was due mainly to the development of lactobacilli and yeasts. That is true because smoked salmon samples were packed in low oxygen permeable plastic bags, which favor the growth of lactobacilli and yeasts.

Coliform bacteria, which was found in unirradiated samples, decreased during the storage period, while fecal streptococci increased. Fecal streptococci, which was found in smoked samples irradiated at 2.0 kGy, disappeared during further storage. Smoked salmon samples irradiated at 4.0 kGy were free from coliforms, fecal streptococci and *Staph. aureus* over the entire storage period, which extended to 4 months at refrigeration temperature.

Concerning *Cl. perfringens* spores, they were detected in both irradiated and unirradiated smoked salmon samples. This is normal and expected, and may be due to the following reasons: (1) the possible presence of *Cl. perfringens* spores in the deep muscle tissue of the raw salmon fish; (2) temperature applied in cold smoking (28–30C) has no effect on *Cl. perfringens* spores; (3) cold-smoked salmon samples were packed under vacuum; (4) cold-smoked salmon samples had a low salt content of not more than 2% and high moisture content, with high water activity enabling the growth of *Cl. perfringens* spores; (5) *Cl. perfringens* spores are among the highly radio-resistant microorganisms. Further study is needed to determine the level of *Cl. perfringens* spores present in cold-smoked salmon and to detect the possible presence of *Cl. botulinum*. These two dangerous bacteria are often implicated in the outbreaks of food-poisoning from smoked fish products.

Sensory Evaluation

Sensory evaluation of color, flavor and texture, which are very important attributes in determining the acceptability of smoked fish products, was done. Selec-

TABLE 4.
SENSORY QUALITY ATTRIBUTES OF COLD-SMOKED SALMON AS AFFECTED BY IRRADIATION AND STORAGE

Parameters	Color			Flavor			Texture		
Storage period [month] / Dose [kGy]	0	2	4	0	2	4	0	2	4
0	8.7	8.2	3.8	8.5	8.3	7.8	8.5	8.3	8.0
1	6.5	7.6	3.5	4.3	7.0	7.5	6.8	7.8	7.7
2	4.5	6.0	3.3	2.8	5.2	7.0	4.2	6.5	7.2
3	---	5.8	3.0	---	3.0	5.8	---	4.3	6.3
4	---	---	3.0	---	---	3.0	---	---	5.0

tion of the optimum irradiation dose used for preservation of cold-smoked salmon depends mainly on the degree of changes in sensory properties. The test panel found no objectionable color, flavor and texture changes of the smoked salmon irradiated at 2 kGy, but they observed marked changes in the color of the samples subjected to 4 kGy. The irradiation dose of 4 kGy damaged the color of smoked salmon samples as the normal cherry red color of these samples was changed to beige-white. In 1961, Sieling stated that there was a distinct color loss in fresh salmon steaks treated with ionizing radiation at levels of 2, 5 and 10 kGy. On the other hand, an irradiation dose of 4 kGy slightly affected the flavor and texture of smoked salmon. Slusar and Vaisey (1970) found no differences in flavor and texture between unirradiated smoked white fish samples and those irradiated at 3, 4, and 5 kGy.

During storage, all the sensory scores, especially those for flavor, tended to decrease as the storage period increased. The rate of decrease in these scores was much higher for unirradiated samples than for irradiated ones (Table 4). It is obvious from the results that flavor was the limiting factor affecting the acceptability and storage stability of smoked salmon samples. The rejection level of flavor scores ($\leqslant 3$) for unirradiated samples was reached at the second month of storage at 2–3C. The rejection level for 2-kGy irradiated samples was reached at the third month of storage, while 4-kGy irradiated samples did not reach the rejection level of flavor scores even at the fourth month.

It can be concluded that the loss of cherry red color in smoked salmon subjected to 4 kGy of gamma irradiation was the limiting factor affecting the acceptability of these products. Although a gamma irradiation dose of 4 kGy was efficient in the destruction of coliform bacteria and fecal streptococci in addition to lowering, to a great extent, the other microbial counts, it reduced the normal pink color of smoked salmon. The maximum gamma irradiation dose recommended for radurized cold-smoked salmon is 2 kGy. This irradiation dose extended the shelf-life of cold-smoked salmon samples to about 3 months at refrigeration temperature (2–3C) and, apart from *Cl. perfringens*, improved their hygienic quality to a large extent.

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BOOK REVIEW

Advances in Food Engineering. Edited by R. Paul Singh and M.A. Wirakartakusumah. Marcel Dekker, Inc., 270 Madison Ave., New York, NY 10016. 655 pages. $195.00.

The field of food engineering has been undergoing a very significant transformation during the past two decades, becoming a recognized and respected discipline. the areas of research traditionally falling into the scope of this field have always been more or less important components of food technology, agricultural engineering, chemical engineering and mechanical engineering, but the development of a viable, recognized and active field is new. As a result there has been a proliferation of meetings devoted to advances in this field, and the present volume presents the proceedings of a workshop held in Jakarta, Indonesia, in September of 1991. The broad topics discussed at the workshop seem very well chosen to reflect the key endeavors of academic, as well as industrial research groups, namely:

I. Water relations and their role in dehydration processes.
II. Measurement of food properties, and their role in optimizing food processing operations.
III. Advances in heat and mass transfer and their application in improving food processing operations.
IV. Innovations in equipment design.
V. Structure and rheology.
VI. Reaction kinetics.

In addition one section is devoted to research in the host country — Indonesia. As a whole the volume of 655 pages is well-edited and printed, and the publication within a few months after the workshop is highly commendable. With respect to the content of the individual papers, which is of course the heart of the matter, this book has the usual merits and faults of workshop proceedings, namely a wide range of approaches but also considerable variations in depth, style and "up-to-dateness" of the coverage of each topic. This is particularly true in the case of the first half of the book containing sections I–IV. As an example, the "water relations" section is introduced by a very cursory and elementary introduction, followed by a very well-done review of flavor retention in drying. The remain-

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ing chapters in this section deal with more specialized topics: two papers on the use of NMR in diffusion studies, a description of two mathematical approaches to mass transport analysis, and a very brief paper on the use of chitosan membranes in osmotic dehydration. Similar variability is noted in the other sections. To use a food-related metaphor, therefore, this part of the book represents a "buffet" from which the reader may sample particularly attractive "morsels," rather than a well-planned meal. The "morsels" in the first four sections which attracted the present reviewer included the papers in the use of NMR in studies of diffusion (in drying and frying) and of flow, a brief but instructive review of ohmic heating, studies on microwave heat transfer and a very basic, but useful analysis of CA storage. These sections also contained two interesting papers from Japan dealing with management aspects of food engineering, namely the utilization of innovations and quality management.

Section V deals with structure and rheology, is 150 pages long and is the most coherent part of the proceedings. The topics covered include reviews of advanced techniques, theoretical aspects of rheology, and include examples of application to specific industrial problems.

Section VI on reaction kinetics, packaging and storage must be considered a "sampler." Two papers deal with indicators of conditions related to packaged food deterioration, and there is the "to-be-expected" competent review of shelf-life prediction from Labuza *et al.*

The final section dealing with Indonesian food engineering is introduced by a timely discussion of the role of industry/university cooperation, and presents several recent Indonesian studies in food engineering.

In general the professional standards of the authors and of the editors are good, with very few serious lapses. One of the annoying aspects is the observed tendency of several authors to fail to cite important previous work in the field they are discussing.

The book is an important resource for all food engineers, and belongs in all industrial and academic reading rooms and libraries. Individual food researchers, especially those dealing with physical properties of foods of importance in food processing would also profit from the availability of this book on their bookshelves.

MARCUS KAREL

GUIDE FOR AUTHORS

Typewritten manuscripts in triplicate should be submitted to the editorial office. The typing should be double-spaced throughout with one-inch margins on all sides.

Page one should contain: the title which should be concise and informative; the complete name(s) of the author(s); affiliation of the author(s); a running title of 40 characters or less; and the name and mail address to whom the correspondence should be sent.

Page two should contain an abstract of not more than 150 words. This abstract should be intelligible by itself.

The main text should begin on page three and will ordinarily have the following arrangement:

Introduction: This should be brief and state the reason for the work in relation to the field. It should indicate what new contribution is made by the work described.

Materials and Methods: Enough information should be provided to allow other investigators to repeat the work. Avoid repeating the details of procedures which have already been published elsewhere.

Results: The results should be presented as concisely as possible. Do not use tables *and* figures for presentation of the same data.

Discussion: The discussion section should be used for the interpretation of results. The results should not be repeated.

In some cases it might be desirable to combine results and discussion sections.

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DEWALD, B., DULANEY, J.T. and TOUSTER, O. 1974. Solubilization and polyacrylamide gel electrophoresis of membrane enzymes with detergents. In *Methods in Enzymology,* Vol. xxxii, (S. Fleischer and L. Packer, eds.)pp. 82–91, Academic Press, New York.

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ZABORSKY, O. 1973. *Immobilized Enzymes,* pp. 28–46, CRC Press, Cleveland, Ohio.

Journal abbreviations should follow those used in *Chemical Abstracts.* Responsibility for the accuracy of citations rests entirely with the author(s). References to papers in press should indicate the name of the journal and should only be used for papers that have been accepted for publication. Submitted papers should be referred to by such terms as "unpublished observations" or "private communication." However, these last should be used only when absolutely necessary.

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ACTIVITY OF POTATO ACYL-HYDROLASES ON NEUTRAL LIPIDS, GALACTOLIPIDS, AND PHOSPHOLIPIDS

Description of experimental work or explanation of symbols should go below the table proper.

Figures should be listed in order in the text using Arabic numbers. Figure legends should be typed on a separate page. Figures and tables should be intelligible without reference to the text. Authors should indicate where the tables and figures should be placed in the text. Photographs must be supplied as glossy black and white prints. Line diagrams should be drawn with black waterproof ink on white paper or board. The lettering should be of such a size that it is easily legible after reduction. Each diagram and photograph should be clearly labeled on the reverse side with the name(s) or author(s), and title of paper. When not obvious, each photograph and diagram should be labeled on the back to show the top of the photograph or diagram.

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Short notes will be published where the information is deemed sufficiently important to warrant rapid publication. The format for short papers may be similar to that for regular papers but more concisely written. Short notes may be of a less general nature and written principally for specialists in the particular area with which the manuscript is dealing. Manuscripts which do not meet the requirement of importance and necessity for rapid publication will, after notification of the author(s), be treated as regular papers. Regular papers may be very short.

Standard nomenclature as used in the biochemical literature should be followed. Avoid laboratory jargon. If abbreviations or trade names are used, define the material or compound the first time that it is mentioned.

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